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CONTENTS

MINUTES OF PROCEEDINGS

	PAGE
Rocket and Satellite Instrumentation Symposium, London, 1 September 1960	3
Symposium on Navigation and the Early Exploration of the Moon, London, 18 November 1960	131
Symposium on Liquid Hydrogen as a Rocket Propellent, London, 28 April 1961	171
Sixteenth Annual General Meeting, London, 15 September 1961	313
Symposium on Materials in Space Technology, London, 22 November 1961	319

PAPERS AND DISCUSSION

	PAGE
An Outline of the British Space Research Programme. By M. O. Robins, M.A., F.Inst.P.	1
Instrumentation for the First Anglo-American Scout Satellite. By A. P. Willmore, B.Sc., Ph.D.	11
Ultra-Violet Observations from Satellites. By J. Ring, B.Sc., Ph.D., F.R.A.S.	17
Ground Equipment for Radio Observations on Artificial Satellites. By B. G. Pressey, M.Sc.(Eng.), Ph.D., M.I.E.E.	20
The Measurement of the Performance of Liquid Propellent Rocket Engines. By A. W. T. Mottram, B.Sc., A.M.I.Mech.E.	28
An Equipment for Processing Time-Multiplexed Telemetry Data. By R. J. McLauchlan, B.Sc., Grad.Inst.P., M.I.R.E. and T. T. Walters	33
Some Problems Encountered in the Design of Large Rocket Engine Test Beds. By R. H. B. Forster, B.Sc., M.I.Mech.E. and L. Breen	55
Optimum Trajectory of n-Stage Missiles. By Harry W. Harcrow, A.B.A., B.S.	70
Minimum Energy Entry into Planetary Satellite Orbits. By S. W. Greenwood, M.Eng., A.M.I.Mech.E., A.F.R.Ae.S.	73
A Preliminary Study of Thermonuclear Rocket Propulsion. By J. Reece Roth, S.B.	99
Minimum Energy Entry into Planetary Parabolic Orbits. By S. W. Greenwood, M.Eng., A.M.I.Mech.E., A.F.R.Ae.S.	108
Shielding Manned Space Vehicles from Space Radiations. By N. K. Ganguli, M.S., Ph.D. and J. T. Lence, B.S.	110
The Relation between Height Error and Elevation Error for an Earth Satellite. By K. H. Fea	114
Report of Council for the Year Ended 31 December 1960	118
The Demands of Nearly Parabolic Lunar Trajectories on Differential Correction and Perturbation Theory. By Professor Samuel Herrick	131
Guidance of Space Vehicles by Radio Measurements and Command. By A. R. Maxwell Noton, B.Sc., Ph.D.	132
The Role of Inertial Equipment. By D. J. Cashmore, M.Sc., A.M.I.E.E.	138
Surface Navigation on the Moon. By P. A. E. Stewart, F.R.A.S.	149
Minimum Energy Entry into Orbits around Mercury. By S. W. Greenwood, M.Eng., A.M.I.Mech.E., A.F.R.Ae.S.	159
Liquid Hydrogen Production on an Industrial Scale. By T. J. Webster, D.Sc., A.M.I.Chem.E., A.F.Inst.Pet. and K. C. Smith	172
Production, Storage and Handling of Liquid Hydrogen. By Peter C. Vander Arend and William J. Scharle	181
The Use of Liquid Hydrogen in Large-Scale Rockets. By A. V. Cleaver, F.R.Ae.S.	189
The Design of Rocket Engines Burning Hydrogen as Fuel. By D. Hurden, B.A., A.M.I.Mech.E.	192
Optimum Engine and Vehicle Coupling for Satellite Launching Stages Using Liquid Hydrogen. By M. S. Hunt, M.Eng., A.F.R.Ae.S., and B. G. White, B.Sc.	199
The Use of Liquid Hydrogen in the Third Stage of a Satellite Vehicle. By A. B. Bailey, G. I. Mech.E., A.M.A.S.M.E., R. G. Cruddace, B.Sc., M.A.R.S. and B. W. A. Ricketson, M.A., D.Phil.	203
Liquid Hydrogen as a Working Fluid in Advanced Propulsion Systems. By P. A. E. Stewart, A.R.Ae.S.	225
The Use of Hydrogen in Nuclear Rockets. By O. H. Wyatt, M.A., Ph.D., A.M.I.Mech.E.	240
Behaviour of Liquid Hydrogen in a Space Environment. By Kurt R. Stehling, M.A.	245
The Blue Streak Rocket Propulsion System. By A. V. Cleaver, F.R.Ae.S.	259
The Effect of Atmospheric Drag on the Orbit of a Spherical Earth Satellite. By D. G. Ewart, B.Sc., Ph.D., F.R.A.S.	269
Some Optical and Kinematical Effects in Interstellar Astronautics. By Prof. Dr. Ing. E. Sänger	273
The Hazard of Corpuscular Solar Radiation to Manned Spaceflight. By C. J. Waddington, Ph.D.	277
Minimization Conditions for Powered Trajectories. By George F. Forbes, M.S. and Alvano Dean	281
Presidential Address: Some Aspects of Recent Progress in Astronautics. By W. R. Maxwell, B.Sc., Ph.D.	295
The Scientific Necessity for a Rocket Network in Europe. By Heinrich Faust, Dr.Sci. Nat.	306
Entry into Circular Planetary Satellite Orbits. By S. W. Greenwood, M.Eng., A.M.I.Mech.E., A.F.R.Ae.S.	310
A General Survey of the Materials Problem. By Professor A. J. Murphy, M.Sc., F.I.M., F.R.Ae.S.	320
Polymers in Space. By N. H. Langton, M.Sc., Ph.D., A.M.Brit.I.R.E., A.Inst.P. and A. L. Soden, B.Sc., A.R.I.C., F.I.R.I.	329

PAGE

Magnesium in Space Technology. By E. F. Emley, B.Sc., Ph.D., F.R.I.C., F.I.M. 340
Aluminium in Space Engineering. By E. G. West, B.Sc., Ph.D., F.I.M. 354
High-Strength Steels. By F. J. Wilkinson, B.Sc., A.M.I.Mech.E., A.M.I.E.E., A.M.Inst.W. 361
The Development of Nozzle Materials. By D. Bunting, M.Sc., Ph.D. 362
The Use of Graphite in Space Technology. By A. E. S. White, B.Sc., A.R.C.S. and R. K. Hurden 367
The Effect of the Radiations Encountered by Materials in Space. By R. S. Barnes, M.Sc., F.Inst.P. 377
The Chemistry of the Lunar Surface. By Michael H. Briggs, M.S., F.R.A.S. 386
Surface Roughness of the Moon. By H. S. Hayre, B.A., D.Sc. 389
Preliminary Study of Propulsive Fluid Accumulator Systems. By Serge T. Demetriades, A.B., M.S., Mech.Eng. 392
Earth Satellite Motion by General Perturbations. By E. D. Zambelli, B.S. 402
Report of Council for the Year Ended 31 December 1961 409
Presidential Address: Some Aspects of the Origins and Early Development of Astronautics. By W. R. Maxwell, B.Sc., Ph.D. 415
The Control of the Rate of Thrust Build-up in a Liquid Propellent Rocket Engine. By S. L. Bragg, M.A., S.M., A.M.I.Mech.E., A.F.R.Ae.S. and V. A. Wallace, B.Sc. 426
The Distribution of Life in the Solar System: An Evaluation of the Present Evidence. By Michael H. Briggs, D.Sc., F.R.A.S., A.N.Z.I.C. 431
The Free Body Motion of Earth Satellites and Associated Radio Effects. By E. Golton, B.Sc. 437

OTHER ITEMS

PAGE

Accounts 117, 120, 407, 408
Annual General Meetings: Agenda 116, 407
Book Reviews 128, 168
B.I.S. News 43, 77, 121, 162, 255, 284, 315, 383, 411, 443
Correspondence 40, 75, 115, 161, 250, 282, 311, 382, 405, 441
Editorials 1, 53, 97, 129, 169, 257, 293, 317, 385, 413
Joint Activities 44, 81, 121, 256, 287, 316, 384, 444
Lectures 83
Obituaries 162
Other News 83
Personal Notes 83
Personalities 80, 294

ASTRONAUTICAL ABSTRACTS

PAGE

1. Astronomy 45, 84, 122, 163, 288
2. Physics 45, 84, 122, 163, 288
3. Chemistry and Materials 46, 85, 123, 288
4. Biology and Medicine 46, 85, 123, 164, 289
5. Aviation and Aerodynamics 47, 87, 124, 164, 290
6. Astronautics 47, 88, 124, 165, 290
7. Propulsion 49, 91, 125, 166, 291
8. Missiles 51, 94, 127, 167, 292
9. Radio and Electronics; Communications 52, 95, 127, 167, 292
10. Planetary Engineering 52
11. Biography and History 52, 96
12. Space Law; Sociology 52, 96, 128, 292
13. Miscellaneous 52, 96, 128

JOURNAL OF THE
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A Year of Promise

The Strasburg conference has been held and we are now awaiting the decisions of the participating nations. While we cannot take it for granted that all the decisions will be favourable, it seems probable that few, if any, of these nations will refuse to participate in the proposed technological space programme. West Germany seems the least enthusiastic, although prepared to cooperate to some extent. Presumably this lack of enthusiasm is the result of weighing the proposed German financial contribution against the work likely to be allocated to Germany and the other benefits which may be received (the contribution over a 5-year period is £13,244,000, compared with £23,333,000 from Britain and £14,399,000 from France).

This need not prove an insuperable difficulty. The individual contributions must be a matter for negotiation and should be revised from time to time to take account of changing circumstances. They should take into account the benefits received as well as the national income (on which the figures mentioned above are based). But even the proposed figures should prove within the means of Germany in her present prosperity. One thing is certain: Germany can make a valuable contribution to the programme technically as well as financially—it must not be assumed that all their former or potential space technologists have emigrated to Huntsville, Alabama.

Even if the worst comes to the worst and Germany remains aloof, that would not be sufficient grounds for abandoning Eurospace. As it is, Britain and France between them are offering to pay 54% of the estimated cost; if Italy's contribution be added, 64 % is accounted for. These three countries could carry out the programme without other assistance if it were spread over eight years, instead of five.

There is thus every prospect that 1961 will see a start made on the development of a European satellite launch vehicle. If progress to this stage has been slow, it is nevertheless true to say that we have progressed further than seemed likely at the time of the first London I.A.F. Congress nearly ten years ago, which first focussed attention on the potentialities of the artificial satellite.

Let us hope that progress during the next decade will also surpass expectations—it should do, because our present expectations are not great. The Anglo-French proposals regarding Eurospace can only be regarded as the absolute minimum. They represent bottom gear, which has to be used to get things moving; once that has happened, a higher gear must be engaged as soon as possible. It is only fair to add that we must also be prepared to accept a change-down when conditions necessitate it—an eye must be kept on what the rest of the traffic is doing. The

Eurospace programme should supplement those of U.S.A. and U.S.S.R. rather than attempt to copy them slavishly, although it is inevitable that some activities must be paralleled. Thus, there is obviously a case for a Eurospace communications satellite as well as an American one, for the same reason that B.O.A.C. and Air France exist side by side with Pan-American and T.W.A.

The coming year shows promise of being a successful one for our precursors in space. America is still attacking the whole gamut of astronautical possibilities, but this year the emphasis will be on getting a man in space; this remains the main Russian objective. The flight of the chimpanzee Mr. Ham in a Mercury capsule and the successful launching of *Sputnik VII* were steps towards this aim, although from different starting points. We expect both countries to achieve notable "firsts" within the next few months: the first manned ballistic flight and the first manned satellite.

This is one activity from which Eurospace must not stand aside. We do not advocate that work should begin immediately on the design of a manned vehicle, although we would welcome this if it should prove financially possible. However, it must be hoped that manned spaceflight will be an ultimate objective of the new organization. When the Government has committed itself to a technological space programme, it must give less weight to those of its scientific advisers who advocate the superiority of instruments over man with religious fervour. Eurospace should initiate a review of the aviation medicine facilities in participating countries and draw up proposals for developing these to cover the special problems of space medicine. This action would be relatively inexpensive but is an essential preliminary to any manned spacecraft project.

1961 is also a year of promise for the British rocket industry. The year began with a revelation of some of the work in progress in the industry made at the well-attended Joint Symposium on Rocket Propulsion, held at the College of Aeronautics. Other aspects are to be surveyed in the Symposia the Society is organizing in the Spring. An important step forward taken by eight leading British firms is the establishment of the British Space Development Company. We offer our felicitations on this "happy event" and look forward to welcoming the new company among our growing group of Corporate Members.

What of the Society in 1961? We look forward to a period of continued expansion, both in membership and activities. The establishment of Eurospace and a British space industry will greatly add to the number of people in this country for whom astronautics is an occupation as well as an interest; they are all potential members of the Society. We hope that existing members will do all they can to promote the growth of our Society. Reference has already been made to the more intensive programme of meetings that has been arranged; we are also increasing the amount of published material supplied to members. *Spaceflight* becomes bi-monthly in 1961—a 20% increase in the number of publications provided. We must not rest content with this increase; we must aim at the publication of a monthly *Journal*.

G. V. E. THOMPSON.

PROCEEDINGS OF THE ROCKET AND SATELLITE INSTRUMENTATION SYMPOSIUM

A symposium on rocket and satellite instrumentation, organized jointly by the British Interplanetary Society and the Society of Instrument Technology, was held at Manson House, 26, Portland Place, London, W.1, on Thursday, 1 September, 1960. Emphasis was placed on work actually being undertaken, or projected, within the United Kingdom during 1960, and for this reason no papers were invited from abroad. Ninety-four persons registered for the Symposium.

Details of the programme are given below and the papers and discussion are reproduced on pp. 4–39 of this issue of the *Journal*. Written communications and correspondence concerning the papers are invited, and should be sent to the Editor for publication.

Joint Organizing Committee

Mr. R. S. Medlock (*Chairman*)

Mr. L. J. Carter	Dr. N. H. Langton	Cmdr. A. A. W. Pollard	Mr E. F. Snare
Mr. D. S. Carton	Dr. W. R. Maxwell	Mr. N. Ream	Mr. F. R. Wyke

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PROGRAMME

Morning Session

Chairman: Dr. W. R. Maxwell (Vice-President, British Interplanetary Society).

Introductory Remarks, by Dr. W. R. Maxwell.

"An Outline of the British Space Research Programme," by M. O. Robins (University College London).

"Instrumentation for the First Anglo-American Scout Satellite," by Dr. A. P. Willmore (University College London).

"Ultra-Violet Observations from Satellites," by Dr. J. Ring (University of Manchester).

Afternoon Session

Chairman: Mr. G. C. Eltenton (President, Society of Instrument Technology).

"Ground Equipment for Radio Observations on Artificial Satellites," by Dr. B. G. Pressey (D.S.I.R. Radio Research Station).

"The Measurement of the Performance of Liquid Propellent Rocket Engines," by A. W. T. Mottram (Bristol Siddeley Engines Ltd.).

"An Equipment for Processing Time-Multiplexed Telemetry Data," by D. J. McLauchlan and T. T. Walters (Bristol Aircraft Ltd.).

INTRODUCTORY REMARKS

Dr. W. R. MAXWELL, B.Sc., Ph.D. (Vice-President), in opening the Symposium, said that he had to apologize for the absence of Dr. L. R. Shepherd, President of the British Interplanetary Society, who was to have taken the chair at the morning session. Unfortunately Dr. Shepherd had been called upon to make a visit abroad; he sent his apologies and had asked Dr. Maxwell to take the chair in his absence. A welcome was extended to all visitors who were present. Unfortunately, not all the papers were available as preprints, but everyone present would be sent a copy of the *Journal* containing the full proceedings of the symposium.

Instrumentation was of scientific and engineering importance in space research, and although there were many people engaged in making instruments and using them, it was probably only a small number of these who really knew very much about the type of instrumentation that was used for this work. One reason for calling the symposium was to make the requirements of instruments in space research and the type of instruments used more widely known.

The first paper would be a description of the British space research programme by Mr. M. O. Robins, who was in the unique position of having an excellent knowledge of this field. Afterwards there would be papers on three different types of instrumentation. Two papers would be concerned with instrumentation that might be used *in* satellites, then there would be one on instrumentation used for tracking satellites, followed by one on instrumentation for analysing data on rocket motor firings. Finally the symposium would conclude with an account of data-processing equipment.

AN OUTLINE OF THE BRITISH SPACE RESEARCH PROGRAMME*

By M. O. ROBINS,† M.A., F.Inst.P.

ABSTRACT

The general organization of civil space research activities in the United Kingdom, and its relations with international organizations, are outlined.

A brief summary is given of the characteristics of the Skylark rocket, of the upper atmosphere research experiments which have been carried out, and of the type of experiments envisaged for the future.

Optical and radio tracking methods used at British-controlled stations for tracking of satellites and space probes are indicated, together with the general nature of the results obtained, and the types of scientific studies which are based on these results.

The general plans for the instrumentation of U.S. Scout satellites with British equipment are discussed, mention being made of the technical and organizational problems which have to be solved in this type of enterprise and of the capabilities of Scout.

In conclusion, attention is directed briefly to the capabilities of British rocket designs for launching Earth satellites.

I. INTRODUCTION

UNLESS the boundaries of Space Research are clearly defined at the outset, the speaker on the subject can easily find himself describing activities in geophysics, astrophysics, astronomy (both radio and optical), astronautical engineering, meteorology, astrobiology, and so on. The list is almost unlimited, therefore a few boundaries will first be defined.

Basically we take space research to mean scientific research carried out by using the techniques of rockets, either for vertical sounding of the atmosphere, or for the launching of Earth satellites. We make our measurements either by using instruments carried in the rockets and satellites, or by observations from the ground of the behaviour of the rockets and satellites under the influence of the various forces in which we are interested.

On this definition, therefore, space research *excludes* researches using balloon-borne instrumentation, and observations from the ground by the instruments of radio and optical astronomy. We also exclude the applications which may follow from the results of the researches—space travel, communication and navigation satellites, and so on. In passing, however, it is worth noting that scientific research into the environmental properties of "space" must inevitably precede any logical programme of space exploration or space travel.

It is a convenient practical definition based on particular techniques, but clearly is artificial in the sense that research into the properties of "space" has been in progress for centuries within the limitations of earth-bound observers.

It is a moot point as to how far one can consider the design of the rockets, satellites, man-carrying space vehicles and the like as space research. Personally, I consider them as engineering tools for the job, and expect advances in their designs to "leapfrog" advances in our knowledge of the space environment—the usual method of progress in fact.

What then have we, the British, been doing about it in the past few years and how are we poised for future work?

I will summarize in historical order, the way things have progressed, and say a little about each aspect in turn.

II. THE BRITISH SPACE RESEARCH PROGRAMME

Apart from many theoretical studies by both professional and amateur enthusiasts, the first steps were taken in the autumn of 1953 by the Gassiot Committee of the Royal Society. With the co-operation of the Director of the Royal Aircraft Establishment, a programme was evolved for the launching of measuring instruments into the upper atmosphere (up to 100 miles altitude) by a specially designed rocket. Government financial support was obtained, the rocket, known as Skylark, was designed and made under the direction of the Royal Aircraft Establishment at Farnborough and Westcott, and the Australian Department of Supply agreed to arrangements for launchings at Woomera. Meanwhile in 1955, five University Groups started development work on experiments of their choice. The first flight trial of Skylark took place early in 1957, and since then many successful flights have carried scientific equipment to the 100-mile altitude region. There is today a well established programme which is not only serving the needs of upper atmosphere research but is also including pilot equipment in preparation for Earth satellite experiments.

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* Paper presented at the Symposium on Rocket and Satellite Instrumentation, 1 September, 1960, organized jointly by the British Interplanetary Society and the Society of Instrument Technology.

† Hon. Research Associate, Physics Department, University College, London, W.C.1.

1. The Skylark Rocket

The Skylark rocket is powered by a Raven solid propellent motor giving a thrust of around 12,000 lb. for ½ min. or more. Altitudes in excess of 100 miles are reached with payloads of up to 150 lb. The whole vehicle weighs about 1 ton, is 25½ ft. long and 17½ in. in diameter. The 15° steel nose cone and the parallel instrument bay provide 5 ft.³ of space for the payload.

A later version of Skylark has an additional short-burning-time booster rocket which gives a considerable increase in maximum altitude.

Telemetry equipment operates on a frequency of 465 Mc./sec. and can provide twenty-four channels of information. There are means available for parachute recovery of the instrument compartment, for ejecting part of the nose cone or for electrically insulating one part from another. It is also possible to carry some instrument sensors in the undisturbed region ahead of the rocket by mounting them on a 4 ft. long spike projecting from the nose cone.

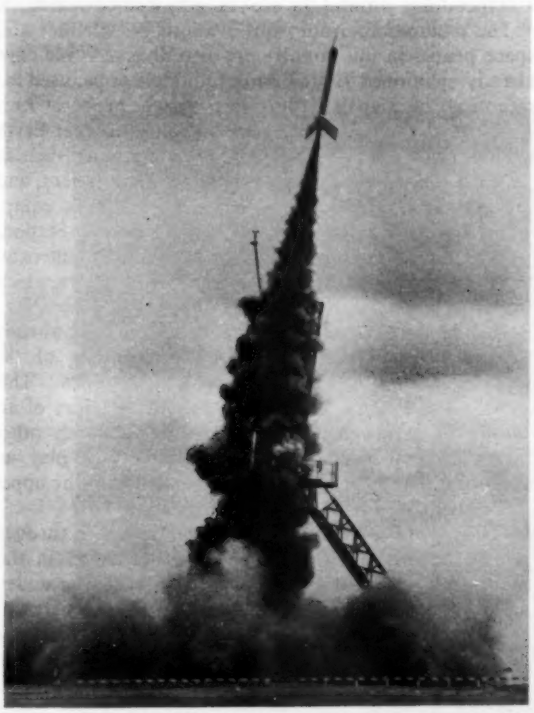

Fig. 1. Skylark leaving launching tower.

There is no doubt that Skylark is a reliable and versatile research rocket giving scope for a variety of valuable scientific measurements.

2. Upper Atmosphere Probe Research

Before mentioning the scientific programme it is perhaps worthwhile stating some of the factors influencing our choice of experiments.

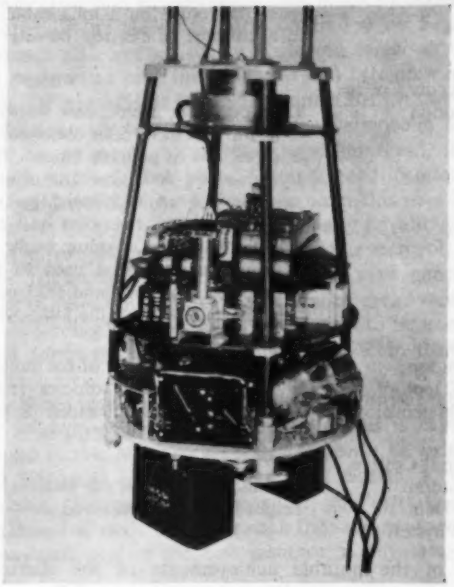

Fig. 2. Instrumentation for early Skylark.

In the first place it must be remembered that the advent of Earth satellites, space probes and the like, while tremendously important and exciting, has in no way diminished the value of rocket research in the atmosphere below say 100 miles. Rockets alone can examine a vertical cross section of the atmosphere in a very short time. Satellites have a useful life only above the 150-mile altitude mark: much of interest lies below this altitude.

We are fortunate to have the use of the Woomera range in the Southern hemisphere; this enables our measurements to be made in geographic and geomagnetic latitudes far removed from those of ranges in North America, North Africa and Russia.

Finally it is vital for the progress of geophysical and related sciences that systematic studies of the diurnal, seasonal and secular behaviour of the upper atmosphere and solar radiation should be made over long periods of time. The glamour of deep space probes and so on must not be allowed to overshadow the value of the patient systematic studies, for throughout the history of science it is such studies that have yielded some of the greatest fruits.

To return to the Skylark programme, during the past few years the following research groups have carried out experiments:

Queens University of Belfast:	Measurement of upper atmosphere winds and temperatures by the observation of sodium clouds released from rockets.
University of Birmingham:	Measurement of ion spectra by the use of positive ion spectrometers ejected

	from the rocket on a long cable, and measurement of electron density by a dielectric method.
University College, London:	Data on upper atmosphere winds and temperatures have been obtained from observations of grenade bursts. Solar Lyman-alpha radiation and solar X-rays have been monitored by nitric oxide ionization chambers and emulsion detectors. Langmuir probe type instruments have been used to study sporadic E ionization and electron and ion concentrations in the ionosphere.
Imperial College, London: (Dept. of Meteorology)	Observations by radar of the motion of clusters of resonant dipoles released from rockets have yielded data on upper atmosphere winds.
Imperial College, London: (Dept. of Physics)	Variations of cosmic ray intensity with height have been measured.

One of the notable achievements of the Australian launching team at Woomera during 1959 was the successful launch of three Skylarks in two days for the International Rocket Week programme.

It is intended that the experimental programmes of the groups mentioned above will continue and expand, while other groups are gradually entering the field; amongst them are the University College of Wales in conjunction with Royal Aircraft Establishment, the Geophysics Department of Imperial College, London, and the Royal Observatory, Edinburgh.

Experiments soon to take place will be concerned with measurements of the geomagnetic field, observations in ultra-violet wavelengths of the southern sky, and ionospheric investigations using radio propagation methods.

In addition to these experiments being carried out in their own right in Skylark, we can expect this rocket to be used for giving test flights to equipment intended for the Scout satellite.

3. Observation of Foreign Artificial Satellites and Space Probes

We now turn to the scientific programmes which have developed in the United Kingdom since the launch of *Sputnik I* in 1957.

It can be fairly claimed that the effort made in Britain to extract the maximum of scientific information from observations of the Earth satellites launched by other countries has not only been on a considerable scale but has been very effective.

It is easy to allow the undoubtedly very great technological achievements of the satellites themselves to overshadow the valuable scientific work which has been and still is in progress, based on optical and radio observations. It would be unfortunate to ignore this work.

Both the optical and radio observations vary in precision and origin. Some are from amateur observers using relatively inexpensive equipment but are none the less of considerable value, particularly in the prediction of satellite orbits of relatively low altitude. Others, from professional astronomers and missile tracking stations are of the highest precision, and some from the Jodrell Bank radio telescope are, of course, unique in that no other known equipment in the world can achieve them.

The methods used for optical observations vary: the simplest in operation is probably a plate camera in which a satellite track, photographed against the star background, is broken intermittently by a coded time mark. The use of kinetheodolites, by trained operators, has been very successful when weather conditions have been favourable, and can give very precise results. At present stations so equipped exist in Scotland, West Wales, Southern England, and there are plans for a site in Malta. Other methods are under development, most of them with the aim of achieving the high accuracy of a kinetheodolite without the use of highly trained operators.

The methods for radio observations of satellites and space probes in this country are also diverse. We have already mentioned Jodrell Bank radio telescope, used for reception of signals from deep space probes. Less sensitive, but adequate for Earth satellites in near-Earth orbits, are the varieties of radio interferometer such as that developed by the Royal Aircraft Establishment, and the American Minitrack system. A Minitrack equipment is being installed near the Radio Research Station, Slough. The output will be of use both for the American tracking network and for any purpose of our own which may arise in the future.

The data from precise optical tracking have already yielded new information about the ellipticity of the Earth and about the effect of air drag on satellites. This latter study, leading to knowledge of the changes of air density at great heights and its variation with other effects such as solar radiation, is bound to play an important part in our developing knowledge of the upper atmosphere.

The study of radio propagation from satellites, through the ionosphere, is being energetically followed in this country and again is bound to lead to a greater understanding of this important region of the atmosphere.

Finally, the tracking information is, of course, the raw data from which the satellite orbit is calculated, and from which predictions of the time and direction of its appearance from any specified station can be made. While it might be expected that orbits well away from the Earth can be calculated and predicted with precision for a long time ahead, this is certainly not so for satellites nearing re-entry and passing through interesting parts of the upper atmosphere. Here the variability of air drag and the changing aspect of the satellite can cause large errors in prediction. The need for accurate up-to-date observations is here very evident. In this country, a satellite Prediction Service is operated by the Radio

Research Station at Slough. This station receives observations from many parts of the United Kingdom, the Commonwealth, and Europe, and issues predictions to all who have a genuine need to know.

Many of you, I suspect, have a greater interest in the contents of satellites than in their external behaviour, so I will leave tracking at this point and turn to our plans and hopes for the direct use of satellites.

4. British Experiments in American Satellites

As is well known to you, we have already arrangements with the American authorities whereby British-designed and -made instruments will be carried in American-launched Scout satellites. There is also the possibility that British satellites might be launched by a rocket system based on the Blue Streak and Black Knight vehicles. Whether or not this plan will take effect is at present undecided.

I will mention the Scout plans first. The offer of the United States to launch equipment designed and made in other countries was made to the members of COSPAR (The International Committee on Space Research) in March, 1959.

It was clear that Britain could gain much by taking up this offer. Our scientists had acquired 4 or 5 years' experience with Skylark experiments and some were in a good position to take the next step into satellite experiments. If it should be decided to launch British satellites with British rockets eventually, early experience in Scout would be of great value. On the other hand, if no British launchings took place, Scout seemed to offer the one certain way for our scientists to enter this new field. This is not to say that there are not many advantages in having a programme entirely under our control, but simply to recognize the fact that the very generous American offer could hardly fail to be of great value to us. Accordingly, plans were made for us to instrument several Scout satellites, to be launched within the next few years.

The Scout satellite-launching system comprises a four-stage solid-propellent rocket booster. This is capable, in broad terms, of placing about 150 lb. in an orbit of about 300 miles altitude. There is, of course, a correspondence between payload mass and orbit. The Americans will undertake to launch the satellites carrying our payload, and in the first instance at any rate, will

Credit: NASA picture by courtesy of "Flight"

Fig. 3. Artist's impression of NASA preliminary proposal for *U.K. Scout I* satellite.

provide us with auxiliary services such as telemetry and power supplies. Launchings will probably take place from a range on the East Coast of U.S.A., and we expect orbits to be achieved which will bring the satellite over this country.

As is usual, most Scout satellites will be "custom built" to meet the needs of particular groups of experiments, but broadly speaking the satellite (Fig. 3) can be thought of as a sphere *c.* 2 ft. in diameter, with antennae and other excrescences as needed. It will enter orbit spinning rapidly about its axis. This not only gives stability, but is advantageous in other ways—such as giving automatic scan for suitably mounted instruments. The availability of solar cells, giving power supplies adequate for a year's operation, and the opportunity to use some of the facilities of the American telemetry and data acquisition network, make Scout a very attractive vehicle for newcomers to the field. Nevertheless, it is not difficult to envisage experiments for which it appears to be unsuited.

The choice of British experiments for incorporation in Scout satellites naturally is restricted to those compatible with the facilities and with other experiments in the same satellite.

It is also necessary that the scientific groups concerned should have prior experience with rocket-borne experiments. It is also, of course, important that an experiment should not mainly be a duplicate—unless there are special reasons—and should fit in sensibly with the international picture of space research. This can be ascertained through the channels provided by COSPAR.

For the first U.K. Scout payload, a natural choice for the "core" of the experimental programme was the direct study of the electrical properties of the ionosphere. Ever since the pioneer experiments of Appleton, British scientists have played a leading part in studying this important region of the atmosphere.

Two research Groups, one under Professor Sayers at Birmingham University and one under Dr. Boyd and Dr. Willmore at University College, London, have been developing the techniques for laboratory study of ionized gases such as the ionosphere. Successful measurements have been made by both Groups with instruments carried in Skylark rockets, and they are now preparing to extend the observations by using the Scout satellite.

Dr. Boyd's group will measure the concentration and mean energy of the electrons in the ionosphere. This group will also determine the nature of the positive ions in the ionosphere, a valuable measurement which will enable the variation in composition of the high atmosphere to be examined. Since the state of the ionosphere is believed to be controlled largely by the Sun, it is important to relate simultaneously the ionospheric measurements with solar conditions. To this end, X-rays and some ultra-violet radiation will be monitored.

An independent and quite different method will be used to measure electron concentration in the ionosphere, by Professor Sayers. This check with Dr. Boyd's measurements should add greatly to the value of both the experiments.

Finally, Prof. Elliott's group at Imperial College, which has carried out many important ground-based studies of cosmic radiation, will be installing equipment to measure the intensity of the heavy component of cosmic rays (Fig. 4 and 5).

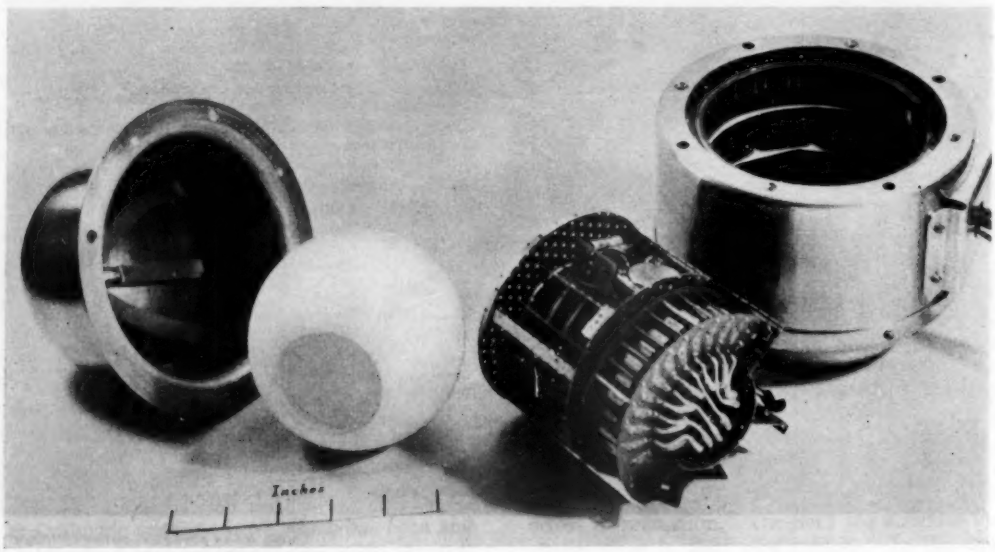

FIG. 4. First prototype of Imperial College cosmic ray instrumentation for *U.K. Scout I* satellite (*housing removed*).

It is almost axiomatic in rocket and satellite design that the payload must be regarded as a complete whole, and the *U.K. Scout I* is no exception in this respect. Quite apart from ensuring that the different sensors do not influence one another, we must design to make the best use of the limited electrical power supplies and the data acquisition facilities. Striking the balance between the needs of the various experiments, and at the same time keeping simplicity and reliability well in mind, means that successive approximations to the final design have to be made. This, of course, would take place for an all-British design just as for a joint U.S./U.K. design.

FIG. 5. First prototype of Imperial College cosmic ray instrumentation for *U.K. Scout I* satellite (*assembled*).

Present arrangements with N.A.S.A. envisage three Scout payloads for U.K. Experiments for the second payload, which is likely to run some 9–12 months behind the first, are being worked out. It is very often necessary to study in considerable detail a set of experiments before one can be sure of compatibility in all aspects. Designs may need to undergo many revisions before the payload is agreed to be practical and worthwhile for all participants.

5. British Satellites for Scientific Research

It is, of course, true to say that the greatest benefits likely to accrue from the U.K. participation in the Scout programme will be in the fields of space science rather than in the technological aspects of instrument and rocket design. We are bound to gain some new experiences in the design of our equipment to withstand the environment in space for a year, but many feel that a full British satellite launching system is needed to fulfil our needs.

If Government approval for such a programme were to be given, what sort of facilities might we expect to have? As is well known, design studies of possible British satellites launched by a combination of rockets based on Blue Streak and Black Knight are in progress at the Royal Aircraft Establishment. Some thought has been given in parallel with these studies, to a matching scientific programme, by Working Groups of the British National Committee on Space Research.

The design studies at the Royal Aircraft Establishment are concerned with two aspects of the problem of putting an instrumented satellite into orbit:

(*a*) determining the best ways of adapting existing or partially developed British military rockets for the launching vehicle;

(*b*) planning the design of satellites which will best meet the needs of the potential customer, in this case the research scientist, although, of course, there are other possible customers, such as communications engineers.

This is not the occasion on which to enlarge on the launching vehicle studies, but a few words on the satellite design studies may be appropriate. A satellite to operate for say, a year, must not only contain long-term power supplies, data storage and transmission facilities, and perhaps attitude-stabilization equipment, but must also have thermal properties which ensure reasonable temperature limits for a variety of conditions of sunlight and darkness. These add up to a formidable set of requirements, and are needed in one of the satellite designs being studied. This satellite, of mass 1750 lb. in a circular orbit of 300 miles altitude, could carry a telescope and spectrometer for ultra-violet astronomy of the stars, and also perhaps a variety of smaller instruments for studying solar radiations over a wide range of the spectrum, and would in fact be an orbiting observatory outside the blanket of the Earth's atmosphere.

A second type of satellite under consideration, some 500 lb. in weight, would contain instruments not stabilized in attitude, but might be capable of penetrating to distances of 8000–12,000 miles. Such a capability would enable extensive studies to be made of the Earth's atmosphere and its radiation, gravitational and magnetic fields.

A third and smaller satellite design capable of very elliptical orbits is also being studied. Such a satellite would extend the scope of measurements to interplanetary regions and to regions where the Sun's atmosphere, rather than the Earth's atmosphere, may play a prominent part.

Such then is the British Space Research programme at the present time. The practical experimental programme, with Skylark, our joint programme with the

American Scout satellites, and our satellites and space-probe tracking activities are modest but useful first steps. If there are to be opportunities for expansion in the future, I think we shall be well placed to take advantage of them.

ACKNOWLEDGEMENTS

The author wishes to thank Dr. J. J. Quenby of Imperial College for providing Fig. 4 and 5. Fig. 1 is Crown copyright reserved, reproduced by permission of the Controller, H.M. Stationery Office.

DISCUSSION

The Chairman, Dr. W. R. MAXWELL,* B.Sc., Ph.D. (Vice-President): What is the time scale of the Scout programme?

Mr. M. O. ROBINS (*in reply*): The first launching of a satellite with our instrumentation should be at about the end of 1961; one would say plus or minus 3 months. The second might be expected to follow after perhaps a 9–12 months' interval, and the third later on.

Mr. P. F. COOK†: In discussing the broader aspects of the British space programme, one has seen previously mentioned that overtures have been made to the Russians—which have been accepted—for instrument space in some of their satellites. For completeness we should like to know what progress has been made in this direction.

Mr. M. O. ROBINS: All I know about those overtures is from statements I have read in the Press, that is, that an individual in this country asked the Russians whether particular experiments could be accommodated in their vehicles. I do not know any more than that at the moment. I do not regard this as being beyond the bounds of possibility.

Dr. J. RING,‡ B.Sc., Ph.D.: I think that Professor Lovell somewhat casually at a recent Conference asked the Russians whether it would be at all possible for some of the Jodrell Bank experiments to be accommodated in Russian satellites. He was given an equally casual answer that perhaps it could be done, and the next move was that the Russians at a Conference in Scandinavia announced that a request had been made. It seems to imply that they will take it up, but I do not think it is definite as yet.

Mr. P. A. T. CHRISTOPHER,§ D.C.Ae., A.F.R.Ae.S. (Fellow): A great deal has been said about the joint European spaceflight programme. As far as I can see the only moves in this direction have come from this country. I do not profess to know anything about what European countries are thinking, but it would be interesting to know whether European countries are in fact actively interested in doing anything of this sort. Can the author quote any work going on?

Mr. M. O. ROBINS: Yes, there are programmes in other European countries, apart from Russia. The French have had an active programme for some time. I do not think that it is on the scale of our admittedly small programme involving the firing of upper atmosphere rockets. The Swedes are interested in upper atmosphere research, and so are the Italians and the Dutch, as well as other European countries. I think they are all looking at this rather carefully to see what it costs, and what can be done. The scientists are all interested and see great possibilities in it. This is one of the growing points of many branches of physical science at the moment, and ultimately I think there will be arrangements whereby scientists in many European countries will be able to launch their equipment either in their own rockets or in those of countries which have access to ranges. The limiting factor is where rockets can be fired. Low-altitude rockets can be fired in Europe, but anything in the 100-mile region needs a proper range, and it is this that will finally decide where the rockets are launched. I think we can look forward to the time when we have international co-operation which will allow—we hope—the interchange of rockets to take the best advantage of the geographical spread of the ranges. It will be useful to make measurements in, say, the northern latitudes of Canada or Sweden and in the Mediterranean. One can do a great deal scientifically by comparing observations of a number of events taken in widely separated regions. This is, of course, an expensive business, and persuading governments to provide funds for this purpose is a lengthy task.

Dr. A. P. WILLMORE,** B.Sc., Ph.D.: To some extent already such programmes exist, but on a very small scale. The initiative for this has been purely scientific. During this summer some French rockets were fired in the Sahara which carried University College equipment, and the objective was to use techniques which the French and ourselves had developed in order to tackle particular problems of the atmosphere, which may yield to a two-pronged attack. Again, there were some experiments using Canadian ranges in connexion with polar cap absorption phenomena. The objective was once again to make a two-pronged attack on the problem. Initiative on the scientific side exists and is already showing some fruit in practical problems.

Mr. D. CARTON,†† A.F.R.Ae.S., M.A.R.S. (Fellow): Writing recently, a gentleman who is not present, in disparaging the use of spaceflight for throwing lumps of metal away from the surface of the Earth, said that it will be difficult for British universities to fill the Scout satellites which were already on order from the Americans. Now I understand that this may not be so, and that University College and others are offering instruments to other organizations. I should like to know whether there is any possibility of various governments in Europe co-operating with us to put instruments into other satellites, and whether we are getting down by way of co-operation to avoiding the duplication of work already being done.

Mr. M. O. ROBINS: As one who has had experience of trying to fit British instruments into Scout satellites I can say that it is like getting a quart into a pint pot!

The question of co-operative experiments in satellites is difficult. The whole business is expensive. A large number of people are engaged for a long time, and one cannot afford to take too many risks. Commencing with the Americans and ourselves, I think this is a two-party co-operative effort which we shall make work. The business of getting instruments from more than two parties begins to make it a little

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difficult. At the moment, to think of more than three parties in one satellite horrifies me! It is something which we shall learn by experience, and ultimately it may be possible to get a co-operative satellite under way. It is as well to remember, of course, that we want co-operation if there is good reason for putting in instruments from different countries.

There is a special working group of COSPAR which considers international programmes for satellites. The contents of the Scout satellites, which are classed as international, are considered by this working group, which includes a number of nationalities who can make helpful comments. The whole business is being carried out in the open with an opportunity for everybody who is interested to say what they think about it.

As regards overlapping, there is not much danger of that at the moment. Over the last few years the number of observations made on points of particular interest and importance have been very few. One does not regard a scientific fact as proved as a result of one spot measurement. One requires corroborative evidence. Therefore, there is not much danger of overlapping, although I think we must pick a middle course from the scientific point of view.

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INSTRUMENTATION FOR THE FIRST ANGLO-AMERICAN SCOUT SATELLITE*

By A. P. WILLMORE, B.Sc., Ph.D.†

ABSTRACT

It is planned in late 1961 to launch a satellite using the Scout launching vehicle, the satellite having been instrumented with apparatus from the Universities of London and Birmingham. The satellite will be a 20 in.-diameter sphere weighing about 150 lb. This contribution describes some of the experiments and the instrumentation which has been designed to carry them out.

The satellite is primarily designed to study the ionosphere, although it contains also a cosmic ray experiment devised at Imperial College, London. The electron density in the ionosphere will be measured by a technique developed at the University of Birmingham by Professor J. Sayers, in which the capacitance of a sphere immersed in the ionosphere is measured in a radio-frequency bridge. The remaining experiments are due to University College, London. Two of these are based on the Langmuir probe technique originally used in the study of gas discharges. In this various parameters of the ionosphere are obtained by a detailed interpretation of the voltage/current characteristic of an electrode placed in the ionosphere. In the first experiment this electrode will consist of a disc which is part of, but electrically insulated from, the satellite skin. In order to analyse the composition of the positively charged particles in the ionosphere, a spherical probe on an arm 10 in. long will be used.

Ionization chambers and proportional X-ray counters will be used to monitor the emission of ultra-violet light and soft X-rays from the Sun, in order to correlate ionospheric storms with disturbances occurring in the atmosphere of the Sun.

I. INTRODUCTION

DURING 1959, following an offer which they had made through COSPAR, the American National Aeronautics and Space Administration agreed to launch a series of three satellites using the Scout rocket, these satellites to contain instruments designed and made in the United Kingdom. In the first of these satellites, *Anglo-American Scout, No. 1*, the experiments will be provided by the groups from Imperial College, London, (under Professor H. Elliot), Department of Electron Physics, University of Birmingham (Professor J. Sayers) and Department of Physics, University College London (Dr. R. L. F. Boyd and the author). This paper briefly surveys these experiments, in particular those provided by the University College group.

II. THE SCOUT VEHICLE

It is perhaps worth describing briefly the Scout vehicle. It has the distinction of being the first American satellite-launching rocket to use exclusively solid propellent motors, of which there are four. This means of course that no in-flight control of the final velocity is possible so that a successful launching demands careful manufacture of the motors in order to obtain a consistent, predictable performance. The first-stage thrust is 100,000 lb. Control of the first stage is by means of both control vanes inserted into the nozzle exhaust and aerodynamic control surfaces at the tips of the four fins. The aerodynamic surfaces are relatively ineffective initially, of course, because of the low rocket velocity.

The second and third stages are controlled by roll, pitch and yaw jet systems using H.T.P., one complete jet system being on each stage. A single guidance package operates throughout the flight, this being placed on the third stage near the junction of the third and fourth stages.

The satellite and the fourth stage are contained behind a nose cone which serves as a heat shield. This is ejected at third-stage ignition. The fourth stage is spun up whilst the third stage is burning, by means of small tangential rocket motors. The spin maintains the motor orientation after separation of the third and fourth stages, when the guidance package becomes inoperative.

Fig. 1 shows a Scout rocket in the launching gantry a few hours before firing, whilst the guidance package is undergoing its final checks. Two Scouts have so far been fired, the second of them successfully. Both of these were probe, not satellite, shots. A number of proving

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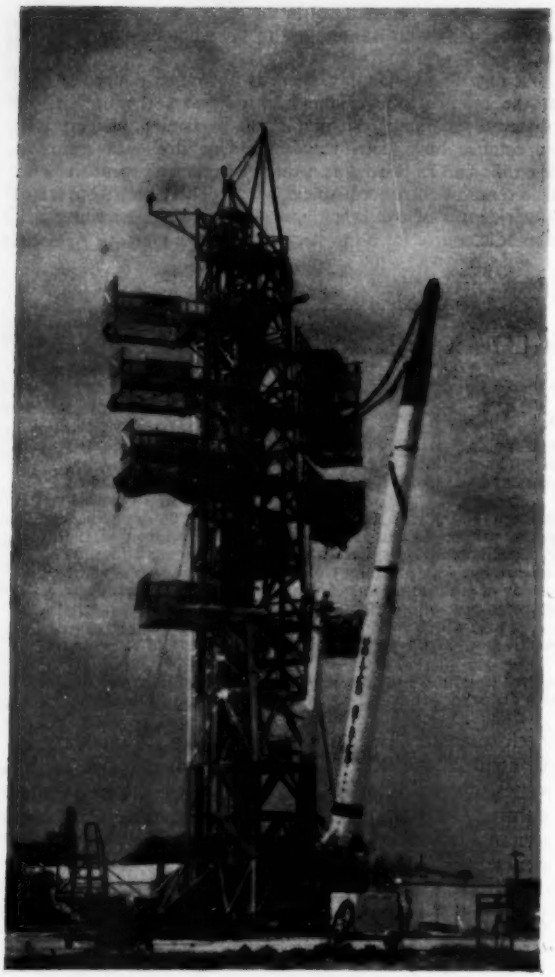

FIG. 1. Scout rocket standing ready for firing on its launcher at NASA's Wallops Island Station in Virginia. Scout is a four-stage, all-solid launcher capable of performing a variety of space research missions. It is 72 ft. tall and weighs approximately 36,100 lb.

rounds have yet to be fired, after which will come the first of the Anglo-American satellites, whose launching date we hope will be near the end of 1961.

In this satellite, responsibility for the instrumentation is divided between N.A.S.A. and the British University groups. N.A.S.A. will provide such parts as telemetry, power supplies and the satellite structure, whilst all the scientific apparatus necessary for carrying out the experiments will be provided by the Universities. The responsibility for conducting the experiments rests entirely, of course, with the Universities. Unfortunately, the design of the satellite has not yet been frozen, so that it is not possible to give any but the most general details of the vehicle.

It is expected, however, that the satellite will be approximately a sphere, roughly 20 in. in diameter, and weighing about 100 to 150 lb. This will be placed in an orbit with an inclination above 50°, so that it will pass at times over Southern England, the perigee and apogee heights being in the vicinity of 200 and 600 miles respectively. The vehicle will contain a telemeter, of course, with an output power of a fraction of a watt, and possibly a solar power supply and we hope, for reasons which will be clear later, a tape recorder for storing measurements during an orbit.

III. INSTRUMENTATION

1. GENERAL

In selecting a group of experiments to go into the satellite, it was clearly necessary to exercise some care in order not merely to duplicate the experiments which are being done both in the U.S.A. and the U.S.S.R., and also in order to take advantage of some of the novel experimental techniques which have been developed in the country as part of the Skylark sounding rocket programme already outlined by Robins[1]. It was therefore decided that the experiments would, with one exception, consist of an integrated set designed to study the Earth's ionosphere and its complex relationship with the Sun. This will be perhaps the most elaborate attack on a single atmospheric problem yet made in this way. The additional experiment is designed to study the intensity and energy spectrum of primary cosmic rays.

In all there are six experiments on board and Fig. 2 is

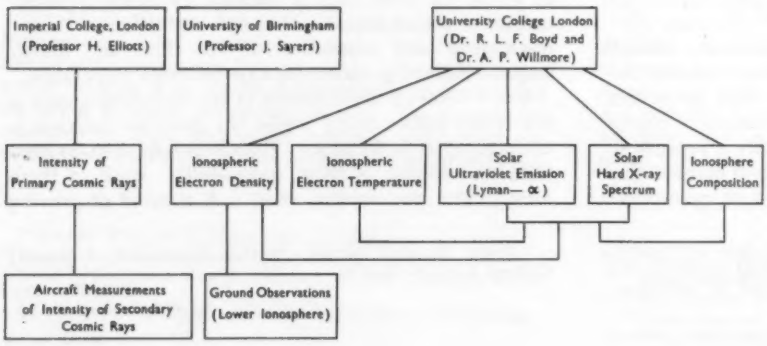
Imperial College, London (Professor H. Elliott)
University of Birmingham (Professor J. Sayers)
University College London (Dr. R. L. F. Boyd and Dr. A. P. Willmore)
Intensity of Primary Cosmic Rays
Ionospheric Electron Density
Ionospheric Electron Temperature
Solar Ultraviolet Emission (Lyman— α)
Solar Hard X-ray Spectrum
Ionosphere Composition
Aircraft Measurements of Intensity of Secondary Cosmic Rays
Ground Observations (Lower Ionosphere)

FIG. 2. Contents of the *Scout* satellite.

a genealogical table showing the groups responsible for them, the parallel measurements which will be made from the ground, and the inter-relationship of the experiments themselves. There are three ionospheric experiments, designed to measure the density and temperature of the electrons in the ionosphere, and the composition of the positive ions (*i.e.*, we wish to know the relative numbers of ions of different species, atomic and molecular oxygen, nitric oxide, etc.). There are also two experiments to measure the intensity of radiation from the Sun in the ultra-violet (including the very bright Lyman-alpha line) and the X-ray parts of the spectrum.

The relationship between these five experiments is shown in another way in Fig. 3. The Lyman-alpha radiation originates primarily in the region just above the visible disc or photosphere of the Sun, in the region known as the chromosphere. The X-rays, on the other hand, come from the corona, high up in the Sun's atmosphere. The intensity of emission of this light from the Sun can vary very widely, particularly the X-rays, and the exact extent and manner of this variation at times of disturbances on the Sun, such as solar flares, are not known. However, by monitoring the Lyman-alpha and X-ray fluxes from the Sun for a year we hope to build up a comprehensive picture of the Sun's behaviour which covers virtually the whole extent of its atmosphere.

Moreover, these rays are directly important in the atmosphere. As Fig. 3 shows, the Lyman-alpha light is thought to be largely responsible for the D, or lowest, region of the ionosphere whilst the X-rays are partly responsible for the E region. Thus, we shall look during the life of the satellite for a correlation between the state of the ionosphere and the state of the Sun at about the same time.

2. Cosmic Ray Experiment

Normally, variations in the intensity and energy spectrum of the cosmic ray flux incident on the Earth are deduced from measurements at the ground or in aircraft or balloons of the secondary particles which are generated in the atmosphere by the impact of the primary rays. However, there is no direct experimental knowledge of the way in which the measurements on the secondary particles should be converted into values of the primary flux. In the cosmic ray experiment the primary spectrum will be observed from the satellite and the secondary spectrum at the same time from high-flying aircraft and the functional relation between the two will be determined. It is, of course, much easier to monitor the secondary than the primary spectrum.

3. Measurement of Ionospheric Electron Density

Professor Sayer's experiment consists in measuring the radio-frequency capacitance at a frequency of a few megacycles per second of a parallel plate condenser immersed in the ionosphere at the end of a support arm about 1 m. in length. This capacitance is

$$C = kC_0,$$

where k is the dielectric constant of the ionosphere, and

C_0 is the capacitance of the condenser *in vacuo*.

k is given by

$$k^2 = 1 - \frac{4\pi Ne^2}{m\omega^2}$$

where e and m are respectively the electronic charge and mass,

ω is the angular radio frequency

N is the number of electrons in 1 cm³. ionosphere.

Thus, by measuring C with a radio-frequency bridge, k and hence N can be calculated. The equipment is all transistorised and consumes about 300 mW. power.

4. Langmuir Probe Measurement of Electron Density and Temperature

The electron density and temperature are also measured by the first of the University College probe experiments.

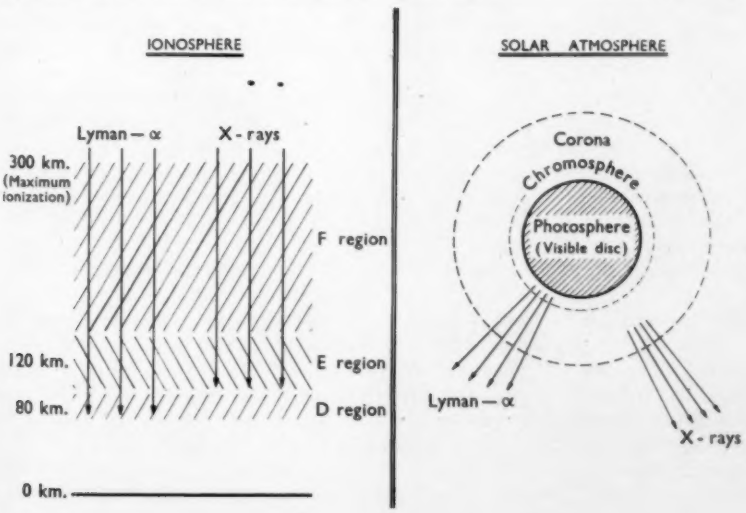

Fig. 3. Relation between five of the six experiments on board the *Scout I* satellite.

It can be shown if an electrode is maintained at a potential V (of the order of a volt or so) negative with respect to the ionosphere, the current which flows is of the form

$$i = i_0 e^{-\alpha V}$$

where i_0 depends in a simple way on the number density of the electrons and other known quantities, and α depends on their temperature. In our case the probe will consist of a disc about 2 cm. in diameter and flush with the outer skin of the satellite (actually the experiment is being duplicated, so that there will be two of these probes).

In order to measure i_0 and α, two sinewave voltages of different frequencies will be applied to the probe, as shown in Fig. 4. The high-frequency one is shown as

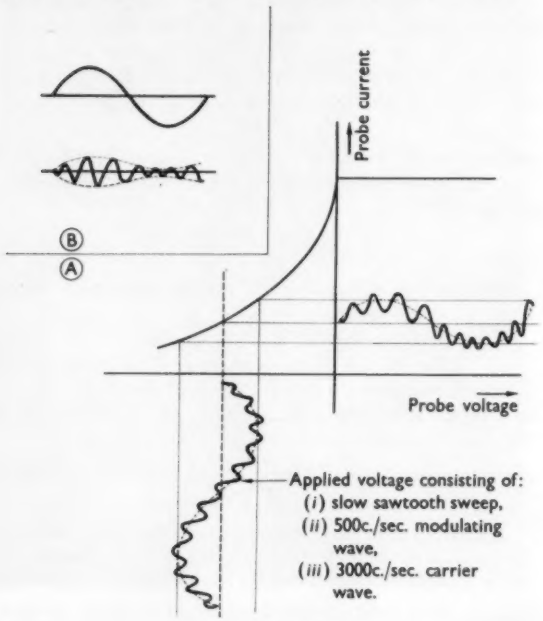

FIG. 4. (*a*) and (*b*)

having a much smaller amplitude for clarity, but in fact the amplitudes are about the same. The low-frequency wave sweeps the high-frequency one up and down the exponential characteristic of the probe, thus modulating it as shown in Fig. 4 (*b*). Clearly the depth of modulation depends on the curvature of the characteristic and hence on α. The high frequency component of the probe current is selected by means of a tuned amplifier and the depth of modulation measured.

The large range of possible values of i_0 requires an amplifier of variable gain, so that the amplitude of the carrier component of the modulated wave is used to provide automatic gain control. The magnitude of the control voltage depends more or less logarithmically on i_0, so that this is also telemetered. It is necessary that the probe shall be on the negative part of its characteristic, and to ensure this a slow sweep is applied to the probe, so that at some time in the sweep conditions are suitable for the measurement.

The circuitry for carrying out this experiment has been entirely designed by engineers of Pye, Ltd., who have turned out a fine piece of equipment. The circuitry, including waveform generators (500 c./sec. and 3 kc./sec. and the 90-sec. sweep) and amplifiers, is contained on two $5\frac{1}{2}$ in. diameter circular cards, forming a stack 2 in. high. The power consumption is 80 mW.

5. Langmuir Probe Measurment of Ion Mass

The ion mass composition experiment is somewhat similar in concept. Because of the high Mach number of the satellite, the velocities of the ions due to their thermal motion are rather small and when viewed from the satellite they effectively appear as a stream moving with the satellite speed. Thus, they have an energy

$$E = \tfrac{1}{2} m V_s^2$$

where m = the mass of the ion,
V_s = the satellite speed,

as measured from the satellite. Thus, the problem of finding the number of ions of a given mass reduces to finding the number of a given energy. Now it can be shown[2] that if the energy distribution function of the ions if $f(E)$, then the second derivative of the current i collected by a spherical electrode in the ion beam at a potential V is

$$\frac{d^2 i}{dV^2} \propto E^{-\frac{1}{2}} f(E)$$

Thus, the problem once again reduces to determining the curvature of the voltage-current characteristic.

The probe we shall use is a 9 cm.-diameter ball. This is biassed positively in order to repel positive ions of increasingly greater energy and would therefore tend to collect a lot of electrons. To prevent this, it is surrounded by a spherical screen 10 cm. in diameter, maintained at a few volts negative to the ionosphere to repel off the electrons. Fig. 5 shows a version of this probe to be flown shortly in Black Knight. A short tubular arm holds the probe clear of the vehicle. The screen is made of nickel 0·1 mm. thick, pierced with 0·75 mm. holes on 1 mm. centres. It is made by an electrodeposition technique, and then the whole assembly is rhodium-plated to ensure a clean oxide-free surface. The curvature of the characteristic is measured in exactly the same way as for the electron temperature probe.

6. Measurement of Solar X-Rays

The most elaborate of the solar radiation experiments is the X-ray measurement. This is being done in collaboration with the University of Leicester. For this, proportional X-ray counters will be used, sensitive in the range 2-16 Å. Two counters will be fitted, arranged so as to give a field of view of 180° in a meridional belt with respect to the spin axis of the satellite. Thus, as the satellite spins, the counters cover the whole sphere about them, and are bound to see the Sun once in each revolution unless, of course, it is obscured by the Earth.

FIG. 5. Langmuir probe to be flown in Black Knight.

A block diagram of the counting equipment is shown on Fig. 6. The counter pulse is amplified by a linear gain-stabilised amplifier. It then passes to a discriminator which passes the pulse only if it lies between two voltage limits differing by a fixed amount. The pulses from the discriminator are totalled by a fifteen-stage binary scaler capable of a maximum counting rate of of 1 Mc./sec. The pulses entering the scaler are controlled by a gate which receives a 1 sec. pulse every 5 sec. Thus a sample of the pulse height distribution is obtained once each 5 sec.

The pulses for the gate also go into a scale-of-five circuit arranged as a staircase generator. The staircase waveform is applied to the discriminator level which thus samples a region of the pulse height spectrum in five steps. Since the height of any pulse is proportional to the energy (and inversely proportional to the wavelength) of the X-ray photon producing it, the result is a wavelength scan of the X-ray spectrum.

The electronics package has been designed by the Guided Weapons Division of Bristol Aircraft Company. It is contained in a 3 in. stack of 5½ in.-diameter circular printed cards, the power consumption being 100 mW. I think it can fairly be said that the performance of this equipment rivals the best that has been built with this sort of power consumption.

7. Measurement of Lyman-α Flux

The remaining experiment, the measurement of Lyman-alpha flux, is the only one whose electronics is actually being built at University College. The photon flux is measured by means of an ionisation chamber whose design owes a great deal to the work on selective detectors for the ultraviolet done by Friedman's group at the Naval Research Laboratory, Washington. However, Friedman's Lyman-alpha chambers are not well suited for satellite use since they deteriorate under long exposure to sunlight. We have designed a suitable chamber which has a lithium fluoride window transparent to radiation of longer wavelengths than 1150 Å. and is filled with iodine vapour which is photo-ionised by radiation of shorter wavelengths than 1280 Å. Thus the chamber is responsive only to light whose wavelength lies between 1150 and 1280 Å., a band which includes the Lyman-alpha line at 1216 Å. The other radiation in

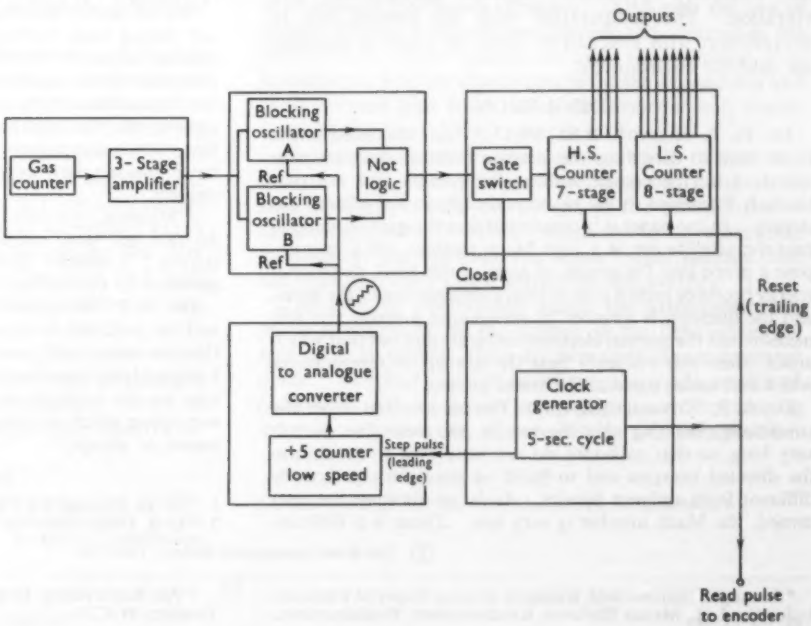

FIG. 6. X-ray spectrometer.

the Sun's spectrum in this band makes a negligible contribution. A problem is the large temperature variation of the vapur pressure of iodine, but with careful design this can be prevented from producing a large variation of the sensitivity of the chamber, which is in fact constant to within $\pm 3\%$ over the range 5° to 45° C. The temperature variations of the chamber are also minimised by arranging a high degree of thermal isolation from the satellite structure, so that the chamber will remain within a few degrees Celsius of the mean temperature of the vehicle (expected to be about 25° C.).

The chamber current is measured by means of an amplifier using a transistor chopper and synchronous demodulator. An amplifier measuring 10^{-8} A. d.c. is shown in Fig. 7. The power drain is 10 mW.

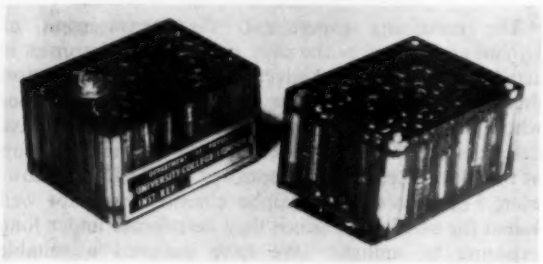

FIG. 7. Amplifier for Lyman-α flux experiment.

All the electronics equipment is transistorized, using (except for a few special cases) silicon transistors. It is designed to work over the temperature range 0 to 50° C. It is constructed by printed circuit techniques on 5½ in. diameter circular cards and will be foam potted to give the necessary protection against acceleration and vibration. The temperature tests are carried out in conjunction with evacuation cycles in order to simulate the satellite environment.

DISCUSSION

Dr. G. P. SILLITO*, B.Sc., Ph.D.: I am interested in the experiment to determine the electron concentration in outer space. I am concerned with rocket motors and am particularly interested in the electron density in the effluent gas stream. In the paper it is mentioned that the gases streaming past the satellite are at a high Mach number. If you interpose a probe into the stream of gases of this kind, directional energy becomes turned into ordinary temperature of the gases, and the question is whether by interposing a probe you will measure not the normal electron concentration but that which arises when you suddenly heat the gas up to temperatures which will ionize some of the atoms present.

Dr. A. P. WILLMORE (*in reply*): The point is that under the conditions obtaining near the vehicle, the mean free path is very long, so that collisions do not have time to randomize the directed energies and to build up densities significantly different from ambient density. As far as electrons are concerned, the Mach number is very low. There is a different situation for electrons than for ions, where the Mach number is high. If one were to try to use these techniques in a rocket motor where the mean free path is not short, these remarks would not be true.

Mr. P. F. COOK†: As to the important question of reliability, I imagine that there are three aspects of this work. First, you may take large quantities of components, continuously test them and select those which seem to be suitable. You can build a large number of equipments and test those. You can, furthermore, use the concepts of parallel redundancy and have more than one equipment in the vehicle itself. I notice that one of the devices was mentioned as being duplicated. Was that because it was thought that this particular instrument was liable to be less reliable, and how was mutual interference going to be avoided between the two? Were you working on the time multiplex principle or the change-over principle? Supposing there are two items and they give different results. Which one do you believe?

Dr. A. P. WILLMORE: So far as the circuitry is concerned, it is in general really rather simple when compared with most sophisticated circuits. The most complex in terms of number of components is the X-ray experiment. Bristols have made a rough estimate of the expected life of the components and have produced a figure of 3 months. This, we believe, means that an experiment might fail within the first 3 weeks, although that is unlikely, and might last for the full year, during which it is hoped that the satellite would be useful. That experiment is the worse case. The others can be expected to last for the full year in which the satellite is in operation.

Our objective in duplicating one experiment was to do all possible to ensure that we obtained results from one experiment at least in the vehicle. If we get different answers from two instruments it gives us some information on the accuracy with which we can interpret the results. The probes will be placed at different points on the vehicle, and we should probably deduce from any difference in their measurements something about the aerodynamic behaviour of the vehicle.

We are neither building large numbers of these equipments nor testing large numbers of components. We have taken existing values of lifetimes for components in estimating the reliability of the equipment. Prototype tests will be carried out on numbers of the order of two or three. All the components are well-tried standard components, with one exception—the iodine chamber. We are not otherwise obliged to have non-standard components whose reliability might be suspect.

A MEMBER: Are you taking precautions to ensure that you do not get stray pulses from radiation coming into the circuits? I believe that semiconductors make reasonable detectors in themselves.

Dr. A. P. WILLMORE: The shielding round the electronics will be sufficient to prevent it being damaged by radiation. On the other hand, we expect the X-ray and perhaps the Lyman-alpha experiments to become inoperative during the time we are in the lower parts of the radiation belt. This is something which we are obliged, by the nature of the experiments, to accept.

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ULTRA-VIOLET OBSERVATIONS FROM SATELLITES*

By Dr. J. RING,† B.Sc., Ph.D., F.R.A.S.

ABSTRACT

The removal of atmospheric absorption enables the astronomer to extend his observations to much shorter wavelengths and many new astrophysical problems can now be tackled. The difficulties of instrumenting an astronomical satellite for ultra-violet observation are discussed and the present position reviewed. A summary of the various astrophysical problems that are to be investigated in this way shows the limitation of the technique both instrumentally and astronomically.

IT is becoming clear to astronomers generally that a major break-through has been made in their science with the advent of space observatories. For many years now, the limit to almost all astronomical observations has been set by the Earth's atmosphere, which distorts the images formed by telescopes and severely limits the wavelength range available for astronomical measurements. There can no longer be any doubt that the means are on hand for launching a large astronomical telescope into orbit and removing both these obstacles.

The first advantage to be derived from a removal of the atmosphere will be in definition. The smallest details which a telescope can theoretically resolve are determined by the diffraction pattern formed at its focus. This smears the image of a distant point of light into a disk, whose apparent angular size depends upon the wavelength of the radiation used and the diameter of the telescope mirror. In principle, using visible light, a 4-in. telescope can resolve detail as small as one second of arc (for example, 1 mile on the surface of the Moon) whereas a 40-in. telescope should allow a resolution of 0·1 second of arc. In practice, the turbulent atmosphere above the instrument will blur the image to one or two seconds of arc, the exact value depending on the site and the quality of atmospheric turbulence at a particular instant.

It is possible, by making a careful selection of the site of an observatory and by using electronic devices, to seize upon the instants when the atmosphere is steady, but, nonetheless, one rarely finds images with blurring of less than one second of arc. Space observations should, in principle, allow full use to be made of the inherent resolving power of a telescope mirror, although, as will be shown later, this possibility introduces many new problems of stability of the instrument, of data handling, and of maintaining optical surfaces to a high degree of accuracy in relatively unfavourable environmental conditions.

The second advantage to be derived from a removal of the atmosphere is the extension of the wavelength range over which observations are possible. From a sea-level observatory, it is difficult to take spectra at wavelengths below 3500 Å., whereas the region of greatest astrophysical interest is at shorter wavelengths. The outer atmospheres of stars are at very high temperatures, which usually results in the atoms being multiply ionized and, consequently, having absorption lines in the ultra-violet. It would be of great interest to the astrophysicist to have spectra of stars in the region from 1000 to 3000 Å. at relatively low resolution and certain narrower wavelength ranges at much higher resolution.

Perhaps the most annoying difficulty which the astronomer faces is the fact that the night sky itself radiates quite strongly compared with some of the objects which he wishes to observe. There are a variety of reasons for this radiation, ranging from the recombination of upper atmosphere molecules which are dissociated during the day by ultra-violet light, to simple scattering of city lights and the light from faint background stars, by the dust, etc., present in the Earth's atmosphere. This gives a constant background intensity to his pictures, which will limit the exposure he can use at his telescope before his plate is completely fogged and ceases to show the details of the sources he wishes to measure. For example, with a camera of photographic speed *f*/5, a sensitive plate will be completely blackened after one or two hours exposure. Although the use of colour filters can sometimes improve the contrast of the astronomical object against this night sky radiation, it is, nonetheless, a severe disadvantage for the astronomer and must prevent him from seeing the faintest and, consequently, the most distant objects.

Once again, satellite observations should remove this radiation but, again, new problems are introduced, in that in order to take advantage of the possibilities of longer exposures, it will be necessary to have accurate guidance of the telescope for much longer periods than are necessary even in the terrestrial observatory.

The type of observation which the astronomer can make is restricted by the nature of the light waves he receives. In general, there are two sorts of measurement made. The first consists in selecting a single source of radiation, such as a star or a galaxy, and measuring intensity as a function of wavelength, *i.e.*, the spectrum

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† Department of Physics, The University, Manchester, 13.

of this object. Alternatively, one can select a particular wavelength or range of wavelengths, and measure the intensity distribution as a function of position in the sky, that is to say, a direct or filter photograph of the heavens. The only other possibility is to measure the degree of polarization of the electromagnetic radiation, but this is usually employed only in certain special cases where the polarization has been influenced, not by the object that emits the radiation, but by the medium through which it travels *en route* to the astronomer's telescope.

Let us consider, first of all, spectrographic observations. For this it is necessary to use a telescope which can be accurately pointed at the object one wishes to study. The light must then be collimated and applied to a diffraction grating, or other dispersing element, and lastly condensed on to some form of detector. It is obvious that the amount of flux received from any object will vary with the area of the collecting telescope, whilst it can be shown that the wavelength resolution for a given accuracy of guidance of the optical system will depend upon the ratio of the size of the diffraction grating to the size of the primary telescope mirror. Such considerations as this lead to the suggestion of about a 20-in. diameter telescope mirror, coupled to a 4-in. diffraction grating, which will allow the astronomer to have a spectral resolution of 1 Å., provided that the telescope can be guided with an accuracy of about 10 seconds of arc. These requirements call for a stabilized platform of some sort in the satellite, but plans are well advanced for the provision of platforms which will be stable to an accuracy of about one second of arc. It is, of course, not really necessary to stabilize the telescope mirror to this accuracy, since smaller optical elements may be employed near to the focus to limit the movement of the image to within the confines of the slit of the spectrograph. It is thus not too difficult to provide the astronomer with the observational equipment needed for this problem, but the problems begin to present themselves when one considers the way in which the data gathered by such an instrument must be transmitted to the surface of the Earth.

The ideal detector for our purpose is, of course, the photographic plate, which would record the whole spectral range between, say, 1000 and 3000 Å., and which, on recovery, could be analysed to give all the information which has been collected by the instrument. Despite the strenuous efforts which are being made to recover capsules from satellites, it seems unlikely that the first few astronomical satellites will be equipped with such a facility, and the astronomer must perforce rely on detectors such as photomultiplier tubes, which will scan the spectrum sequentially and record the variation of intensity, which must then be telemetered back to the ground observer. If we wish to know the intensity in each spectral interval in this wavelength range to an accuracy of 1%, we must transmit about 10^4 bits of information per spectrum.

The ultra-violet light levels of stars are still somewhat uncertain, but the best calculations available at the present time suggest that the satellite-borne spectrograph could observe the spectrum of a single star in each revolution about the Earth, and that the data so acquired could be transmitted back to the ground base in a time of about 15 min., which means that, provided the guidance mechanism of the telescope can be arranged to transfer from one object to the next during the sunlit half of the orbit, in a previously arranged programme, it would be capable of measuring the spectra of about ten stars per day and would have examined all the objects which were sufficiently bright after about one year's work. This information would be of great significance to astrophysical research and it is likely that such a device will be the first astronomical instrument to be fitted to a satellite.

It is when we try to make the second type of observation that the instrumental problems begin to manifest themselves. We can use the lack of absorption in the ultra-violet region of the spectrum to take photographs of fields of stars, from which their ultra-violet brightnesses may be measured. Alternatively, we can attempt to use the higher resolution permitted by the lack of an atmosphere (and also possibly by the decreased wavelength) to take pictures of higher definition than is possible from the surface of the Earth: for example, to reveal greater details of the surfaces of the Moon or the planets. Plans are already afoot in a number of places to use a mirror system, of fairly small aperture, together with an image tube or a scanning photomultiplier, to tackle the first of these problems. But the simplest calculation will show that to explore a field of view 10° across, with a resolving power of 1 minute of arc, will give 360,000 separate picture points which each must be photometered with an accuracy of about 1% if we are to study all the stars in this field and to obtain accurate magnitudes for them. With the bandwidths currently available for satellite telemetry, it might take many hours to transmit to the Earth one such picture, and, clearly, it will be a very long time before even the bright stars of the sky have been completely investigated in this way. However, the situation may be ameliorated if one uses the fact that the positions of the bright stars are already known roughly from visual observations. It is, therefore, only necessary to explore the field quickly, and to transmit back to Earth only the brightness of each point, together with some reference co-ordinate, which will enable it to be identified with the object observed at visible frequencies. No such system has as yet been proposed and perhaps there is a need for research into an apparatus of this type.

If we now try to take advantage of the decreased wavelength to obtain pictures of very high resolution, the difficulties become extremely formidable. We can already see detail as small as one second of arc from the surface of the Earth in favourable circumstances, and, whilst it is theorectically possible to use a 20 in. mirror, working at 2000 Å., to obtain a resolving power ten

times greater than this, one can imagine the difficulties involved in stabilizing the surface of the mirror to the necessary fraction of this short wavelength in its rather unfavourable environment. There will also be great difficulty in guiding the mirror on a fixed point in space whilst the photograph is being taken. When we consider the difficulties of data transmission, we see that to investigate a field of view 1° across, with a resolving power of one-tenth of a second of arc, with 1% accuracy of intensity measurement, leads to an amount of information of the order of 10^{10} bits, which it is out of the question to transmit in a reasonable time, with the equipment at present used or even conceived.

We can see from these considerations, that apart from the normal difficulties of working from satellites, no great obstacle stands in the way of obtaining low-resolution ultra-violet spectra of stars; that one might possibly obtain ultra-violet magnitudes for a large number of bright stars, but that a great deal of work must be done on the problems of data handling from satellites before it will be possible to use extremely high angular resolution. This analysis is reflected rather well if one considers the problems that have already been tackled from rockets or are about to be studied from satellites in the U.S.A. or U.S.S.R. We have seen that the solar spectrum in the ultra-violet has now been obtained over a very wide range indeed and that high-resolution spectra have been obtained for a few interesting lines, such as Lyman alpha. Monochromatic pictures of the Sun have been taken in the light of a single emission line and information has been obtained about the X-ray emission from the solar corona, and is about to be obtained for the region where the solar corona merges into the interplanetary gas. Special types of geiger counters, working at the wavelength of Lyman alpha, have been used to discover rather intense sources of emission, which were at first thought to be extended sources, *i.e.*, nebulae, but which are now believed to be bright stars. Boyd and Butler of the United Kingdom are now attempting to measure the ultra-violet magnitudes of stars from rockets with, of course, the tremendous advantage of the recovery of their photographic plate which such a vehicle offers. One is tempted to speculate on the possibility of observing distant galaxies in the light of Lyman alpha, which, because of their enormous recessional velocities, will have been shifted into the near ultra-violet region of the spectrum. Such observations will tend to be easier from a satellite since one will not have the background of the night sky to contend with in making observations of these faint sources.

Current plans for satellite observations include the proposal in the United States to have a 50-in. telescope mirror in orbit, whose resolving power will be limited only by the diffraction pattern at its focus. It is estimated that some ten years must elapse before this is a feasible proposition. However, in the immediate future, it is proposed to launch an 8-in. telescope camera, to perform three-colour photometry of stars down to tenth magnitude in the ultra-violet region. Many spectrographs are being designed to cover the region 1000–3000 Å., with resolutions of 0·1–1 Å., with which the ultra-violet spectra of O and B stars as faint as fifth magnitude will be investigated over the whole wavelength range. Other spectrometers with 0·01 Å. resolution, obtained by working in a high order of an echelle grating, will be used to study the interstellar absorption lines, which are superimposed on the light from stars by the gas which lies between the star and the observer.

The greatest difficulty in the way of astronomical observations from satellites can be seen to be that of transmitting the information from the telescope back to the observer. One solution to this problem may be to have a manned satellite observatory and it is certain that such a proposal is under consideration in the U.S.S.R. Not only can the skill of the man be used to orient the instrument accurately, but his discriminatory powers may be extremely useful in deciding which information is valuable enough to be telemetered, so avoiding the waste of time involved in working completely in the dark and sending back all the data collected by the instrument, many of which will inevitably be about the dark regions between interesting astronomical objects.

DISCUSSION

Mr. C. E. G. Bailey,* M.A., M.I.E.E., M.S.I.T. (Fellow): There has been a very valuable concentration on questions of principle and questions of communication which can provide a background in terms of which one can discuss the apparatus later.

Continuing on the same line and discussing principles before coming to the apparatus, I should like to refer to the question of searching for individually interesting stars. A large part of an empty sky has to be televised back to Earth in order to discover a particular point, but there is unlimited bandwidth inside a satellite, and there are certain techniques of scanning which were developed originally in radar. For example, a steadily decreasing spiral scan is put on to a given area with initially poor resolution, and whenever anything is picked up, the centre of the spiral is directed towards that area. The spiral is then caused to contract in such a way that the resolution is improved. This results in centring at one particular point, and co-ordinates of that point can be transmitted; information about the immediate neighbourhood of the point can also be added. With a limited amount of storage memory such an arrangement can be induced to neglect completely any object which has been previously scanned so that overlapping fields can be scanned in this particular way.

I should like to ask whether there can be any future for a technique such as this from the point of view of principle, if for example the principle of selection which was mechanical and inside the satellite were confined to examining differences between a certain range of orders of magnitude of brightness.

Dr. J. Ring (*in reply*): One could eliminate redundancy in data by not scanning all points, but make the equipment look

* Solartron Industrial Controls Ltd., Farnborough, Hampshire.

for what you are interested in. In order to do this work we must know precisely what we are looking for so that we can build into the selection system the right characteristics. I feel that interplay between astronomy and communications engineering is what is needed in this case. This may be the sort of thing that we in this country can become good at. One feels that very few people are thinking of anything other than the most crude assembly of astronomical instruments with new methods of putting them up.

I would predict that by the time we get into the satellite field, it is such techniques which have been described that will be needed in order to deal with the refined information which we shall be in a position to obtain.

Mr. P. A. T. CHRISTOPHER*, D.C.Ae., A.F.R.Ae.S. (Fellow): The author stressed the possibility of measuring the structure of the Earth's atmosphere on the assumption that this high resolution could be obtained. Does he seriously think that the programme could go ahead in the next 4 years in which we could determine the structure of the Earth's atmosphere above 200 km. to the sort of accuracy that has been possible in the White Sands experiments?

Dr. J. RING: I think so. In so far as it involves measuring absorption line profiles, then there is no doubt that at the temperatures obtaining at this part of the Universe, and with the densities which are predicted, we shall get the sort of narrow absorption line peak in the background of the ultra-violet radiation which could be looked at with the resolving powers of either interferometers or echelle spectrographs. I think that optical techniques will allow this with ease.

Mr. P. A. T. CHRISTOPHER: I had in mind actual measurement.

Dr. J. RING: Generally with most measurements one is limited by the nature of the source itself being examined. Its temperature is high, so there is no point in using high resolution. If you deal with cold interplanetary gas you get a sharp line in the spectrum and very high resolution techniques are required.

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GROUND EQUIPMENT FOR RADIO OBSERVATIONS ON ARTIFICIAL SATELLITES†

By B. G. PRESSEY,‡ M.Sc. (Eng.), Ph.D., M.I.E.E.
(Communication from the D.S.I.R. Radio Research Station)

ABSTRACT

The radio observations made on artificial Earth satellites at the D.S.I.R. Radio Research Station have a threefold purpose: to provide positional information, to obtain data from the instruments in the satellite and to study the propagation of the waves transmitted from the satellite. Some of the ground equipment used for these purposes is described.

The radio interferometer is the instrument principally used for satellite tracking, and equipments operating on 20, 40 and 108 Mc./sec. are available. The operation and performance of these instruments is discussed.

Positional information is also obtained from the Dippler frequency shift of the received signals and equipment for the precise measurement of such frequency changes is installed at the station.

The recording of the telemetry signals from Russian and American satellites is described and details given of the methods used to analyse the records.

Finally, an indication is given of the way in which the observations may be used to study wave propagation.

I. INTRODUCTION

RADIO is playing a major part in the control and tracking of artificial Earth satellites and space probes and in the recovery of data from the instruments carried by them.

The radio observations made on satellite signals at the D.S.I.R. Radio Research Station at Slough have a threefold purpose: to provide positional information, to obtain data from the instruments in the satellite and to study the propagation of the waves transmitted from the satellite. Some of the ground equipment and measuring techniques used for these purposes are described.

II. POSITIONAL MEASUREMENTS

1. INTRODUCTION

Although the most accurate method of positional measurement is by optical means, either visually or photographically, it has serious practical limitations owing to cloud cover and the low brightness of the majority of satellites. Moreover, there are periods of several weeks' duration when some satellites are not visible from this country because the sky is not sufficiently dark when the satellite is illuminated by the Sun. Thus

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† Paper presented at the Symposium on Rocket and Satellite Instrumentation, 1 September, 1960, organized jointly by the British Interplanetary Society and the Society of Instrument Technology.

‡ Principal Scientific Officer, Department of Scientific and Industrial Research, Radio Research Station, Ditton Park, Slough, Buckinghamshire.

it is essential that facilities for tracking satellites by radio should be provided.

2. Interferometers

The interferometer is the instrument principally used for satellite tracking. Its aerial system (Fig. 1) consists

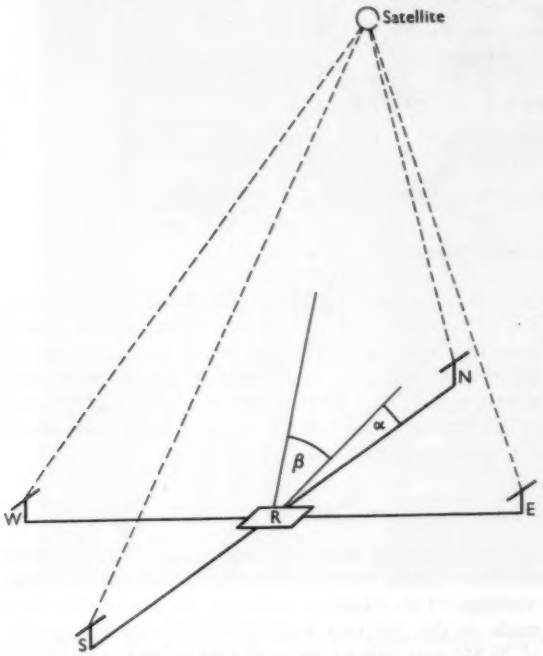

Fig. 1. Radio interferometer for satellite tracking.

of two pairs of spaced aerials with the baselines of the pairs set at right angles to each other. Horizontal dipole aerials mounted three-eighths of a wavelength above the ground are used and the spacing between each aerial of the pair is ten to fifty wavelengths. By means of suitable receiving equipment the phase difference between the signals received at the two aerials of a pair is obtained and from it the difference in the wave-path lengths is computed. Similar simultaneous observations on the other pair of aerials allows the azimuth and elevation of the satellite at a given time to be calculated. There is, however, ambiguity in this determination because of the system's inability to indicate the integral number of cycles in the phase difference. If, however, observations are made simultaneously on a second system with a shorter baseline of one or two wavelengths, in which the alternative directions are more widely spaced, the ambiguity may be resolved.

Several methods of determining the phase difference between the aerial signals are used. In the systems for 20 and 40 Mc./sec. developed by the Radio Research Station only the times at which the signals are in phase or in anti-phase are indicated. This is done by sampling the amplitude of the standing wave produced on the transmission line between the two aerials at two points on the line a quarter-wavelength apart (Fig. 2). The

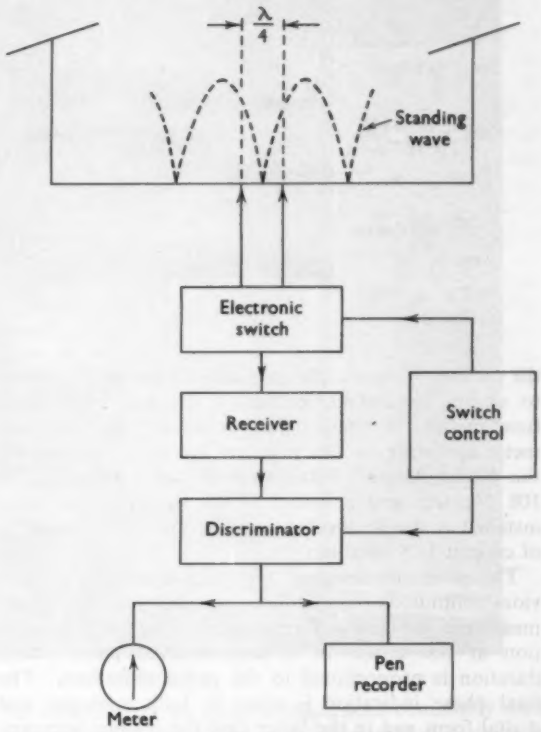

Fig. 2. Phase comparison interferometer for 20 Mc./sec.

receiver input is switched electronically at 100–200 c./sec. between these two points and the rectified output, switched in synchronism, is applied to a centre-zero d.c. meter and a pen recorder. The record thus obtained during a satellite transit shows a succession of crossings of the zero line at each in-phase and anti-phase condition (Fig. 3). With the 150 m. baseline used in the 20 Mc./sec. system there are forty such crossings, which, for high angles of elevation, correspond to directions spaced approximately 4° apart. Fig. 3 also shows the records obtained on the shorter baseline system, 25 m. spacing, for which there are only six crossings corresponding to angular spacings of approximately 24°. A comparison of the two sets of records enables the crossing of the central plane of the baseline to be identified as shown. The direction of arrival of the signals at any other time may be obtained by interpolation to an accuracy of about ½°.

Other methods of phase comparison enable the phase difference to be continuously indicated. By sampling the amplitude of the standing wave on the aerial transmission line at four points one-eighth of a wavelength apart and combining receiver outputs proportional to

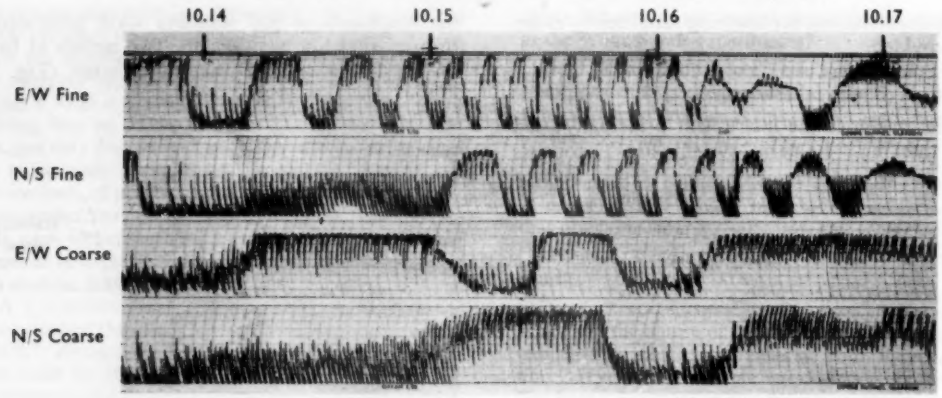

FIG. 3. Typical interferometer record.

the squares of the sample amplitudes it has been possible to obtain continuous records of the sine and cosine functions of the phase difference angle. An interferometer operating on this principle has been designed by the Royal Aircraft Establishment[1] for a frequency of 108 Mc./sec. and a model of the equipment is being installed at the Radio Research Station for the tracking of current U.S. satellites.

The American-designed Minitrack system[2] also provides continuous phase difference indications, the phase measurement being performed in this case by the generation at 500 c./sec. of a unidirectional pulse whose duration is proportional to the phase difference. The final phase indication is given in both analogue and digital form and in the latter case the reading accuracy is less than $\frac{1}{2}°$, which, for a fifty-wavelength aerial baseline, corresponds to a directional sensitivity of 5 sec. of arc at the zenith. An equipment of this type is also being installed at the Radio Research Station. It will operate on frequencies between 136 and 137 Mc./sec., one of the bands recently agreed within the International Telecommunications Union for transmissions from space vehicles.

3. Accuracy of Measurement

The accuracy of the interferometer for satellite tracking is dependent upon three factors: the accuracy of the phase-measuring equipment, the electrical symmetry of the aerial system and the propagation of the radio waves. The internal accuracy of the equipment can be checked by the application of test signals and in order to compensate for aerial asymmetry and local site effects an overall calibration is performed with the aid of a transmitter on a high-flying aircraft. The calibration is carried out at night so that a light on the aircraft can be pinpointed by photographic means against the star background.

When all instrumental errors have been minimized, inaccuracies due to the deviation of the radio waves from the straight line path by ionospheric refraction may still be present. The magnitude of the deviation varies with the angle of elevation, being greatest near the horizon and negligible at the zenith. For example, at an elevation of 45° it is of the order of 2°–3° on a frequency of 20 Mc./sec. and 0·05°–0·2° on 100 Mc./sec. under average ionospheric conditions.

4. Other Types of Directional Equipment

Other types of direction-measuring equipment have also been used at the Radio Research Station for satellite tracking. For example, azimuth measurements were made on the first two Russian satellites on a frequency of 20 Mc./sec. using a conventional cathode-ray Adcock direction-finder. At the present time the tracking of American satellites on a frequency of 108 Mc./sec. is performed on a steerable spaced-aerial system. This consists of four Yagi aerials mounted on the corners of a square of one wavelength side with diagonally opposite aerials coupled together and connected to phase comparison equipment similar to that used for the interferometer. The system is rotated in horizontal and vertical planes until a zero reading on the output meters of both phase comparators indicates that the system is directed on to the satellite. Angular accuracies of the order of 0·5°–1° may be obtained.

A small steerable parabolic reflector is also available for frequencies of the order of 100–1000 Mc./sec.

III. THE RECEPTION AND ANALYSIS OF SATELLITE SIGNALS

1. Receiving and Recording Equipment

The equipment installed at the Radio Research Station for the reception, recording and analysis of signals from satellites and space probes is shown in Fig. 4. The receiver racks are on the left, the multichannel tape

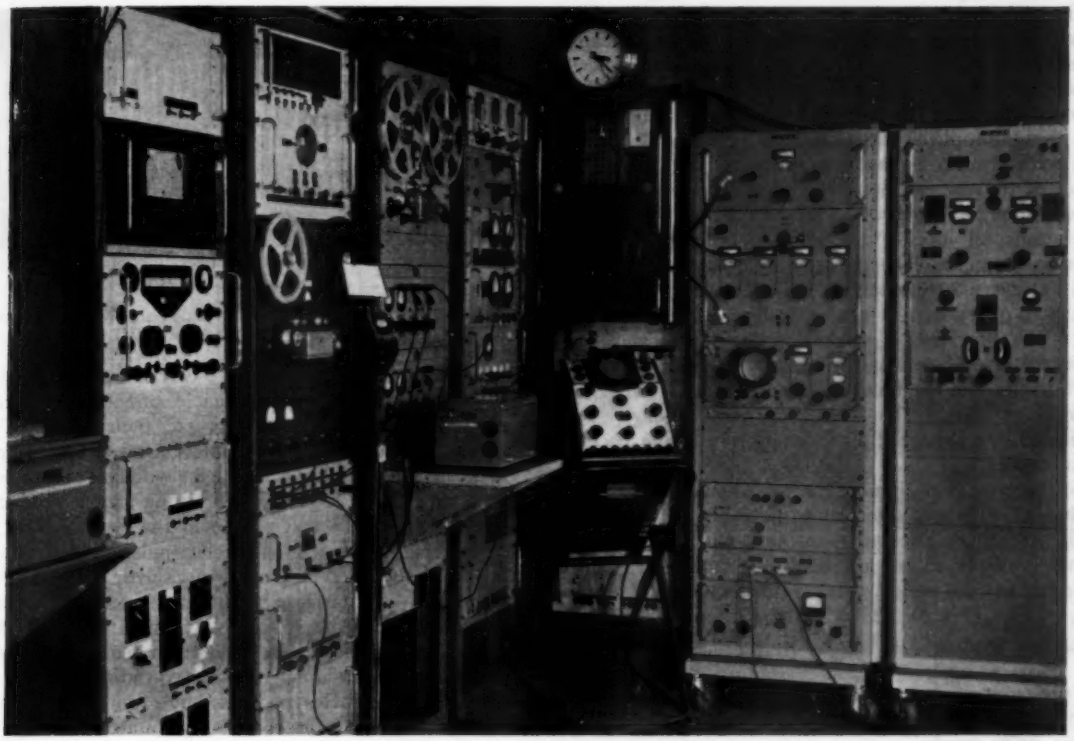

FIG. 4. Receiving equipment for satellite signals.

recorder in the centre, the analysis equipment on their right and the precision frequency synthesizing apparatus on the extreme right. In the field outside the laboratory a range of aerials of various polarizations and directional properties for frequencies from 20 Mc./sec. to 1000 Mc./sec. are available.

The general arrangements for receiving and recording are shown in the block schematic of Fig. 5. Receivers to cover the V.H.F. and U.H.F. bands are available but,

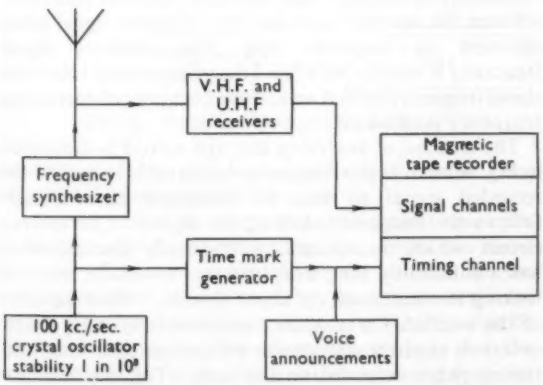

FIG. 5. Receiving system.

for reception on the specific frequencies commonly used for satellite transmissions, crystal controlled converters are used in conjunction with a crystal controlled H.F. receiver to obtain the necessary high degree of frequency stability. A crystal-driven frequency synthesizer provides a reference frequency stable to 1 part in 10^9 for the measurement of frequency shift. Time marks at 1 sec., 10 sec. and 1 min. intervals are also obtained from the crystal oscillator and recorded, together with voice announcements, on a separate channel of the magnetic tape recorder. The number of receivers and recorder channels available permit reception and recording on up to four signals simultaneously. High-speed pen recorders are also available for amplitude recording on seven channels.

2. Analysis of Telemetry Signals

The data obtained by instruments in the satellites are transmitted to ground stations by a radio telemetry link. The telemetry systems vary from one type of satellite to another. For example, there may be a relatively simple keyed-carrier system as was used in *Sputnik III* or they may use a number of audio-frequency sub-carriers with frequency, pulse width or pulse time modulation on them, as in some U.S. satellites, to provide up to forty-eight channels.

As an example of the methods of recording and decoding telemetry signals the extraction of cosmic-ray data from the signals from *Sputnik III* will be described[3]. The cosmic-ray instrumentation in the satellite[4] included a detector consisting of a sodium iodide crystal and a photomultiplier. The anode and dynode currents from the photomultiplier charged capacitors whose discharge at a predetermined voltage operated a relay. The magnitudes of the currents were indicated, therefore, by the time of charge, *i.e.*, the time interval between successive operations of the relays. The counting rate was measured similarly using a scaler which operated a third relay at every 2048th impact. The signals transmitted consisted of a group of four pulses with a period of 1·23 sec. The first was a marker pulse, the second was believed to indicate whether solar or chemical batteries were in use and the third and fourth pulses carried the cosmic-ray data. The operation of the relays was indicated by a change of pulse duration from one discrete value to another.

In the ground equipment the received signal is mixed with a r.f. reference signal and the resultant audio beat signal recorded. For analysis purposes the recorded signal is displayed on a cathode-ray tube whose time base has a sweep period equal to that of the pulse group, *i.e.*, 1·23 sec. (Fig. 6). The time base is not synchronized

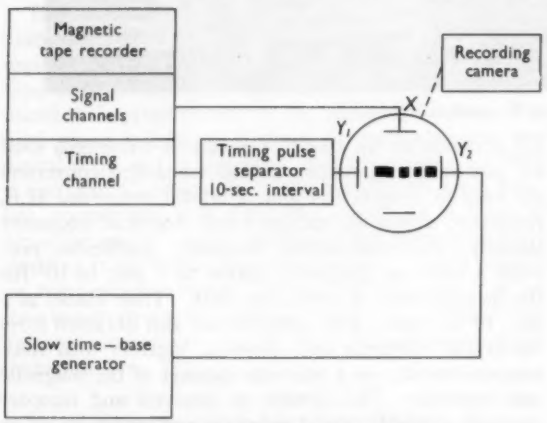

FIG. 6. Analysis of telemetry signal.

to the signal, but it is of high stability and is adjusted to give a stationary pattern on the tube screen. The pattern is recorded on a photographic film moving transverse to the display so that a raster type of record, as shown in Fig. 7, is obtained. 10-sec. time marks are also recorded on the edge of the film by interrupting the trace produced by the second beam of the oscilloscope. From this record the time intervals between the changes of pulse duration and, hence, of relay operation, can be readily measured and the ray intensities and count rates calculated using the calibration data provided.

With more complex telemetry systems such as that used in *Explorer VII* it is necessary to demodulate the

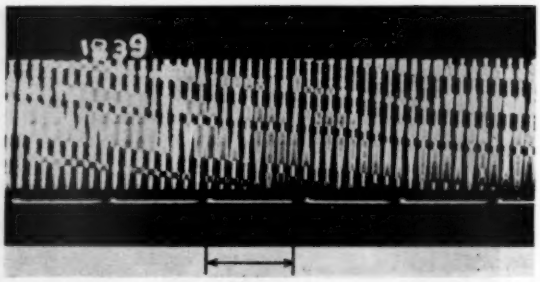

FIG. 7. Record of telemetry signals on 20 Mc./sec. from Satellite $1958\delta_2$ (*Sputnik III*).

signal and record the audio sub-carrier signals, which in this satellite have centre frequencies of 560, 730, 960 and 1300 c./sec. The sub-carriers are then separated by filters and the frequency modulation on each converted to d.c. as shown in Fig. 8. The d.c. voltages are recorded on a paper chart together with timing marks, producing records similar to that shown in the figure. The 560 c./sec. channel provides reference pulses at half-second intervals divided into groups of twelve; the 730 c./sec. channel gives data from radiation balance measurement in binary code; the 960 c./sec. channel is commutated every 1·5 sec. to provide data from ten measurements including Lyman-alpha and X-ray radiation; and the 1300 c./sec. channel is modulated by a four-step frequency shift to give data from cosmic-ray counters.

3. Measurement of Doppler Frequency Shift

The change in frequency of the signal received at a ground station from a satellite transmitter moving past the station can be used to determine the position and speed of the satellite. This frequency shift is of the order of 600 c./sec. for low-flying satellites transmitting on 20 Mc./sec. and increases with the transmission frequency and the speed of the satellite. As already indicated (Section III.1) the shift is measured with the aid of a reference frequency of high stability, the beat frequency between the satellite signal and the reference signal being recorded on magnetic tape. The reference signal frequency is usually set a few kilocycles/second below the signal frequency so that an audible beat note of decreasing frequency is obtained.

The method of analysing the tape record is illustrated in Fig. 9. An audio frequency oscillator is locked to the recorded signal so that its frequency automatically follows the frequency shift of the signal. The locking circuit, which incorporates a frequency discriminator, has a sufficiently long time constant to ensure that the locking is maintained on keyed signals. The frequency of the oscillator is measured automatically every 5 sec. or less on an electronic counter which is gated by the 1-sec. timing pulses recorded on the tape. The measurement is thus independent of any differences between the

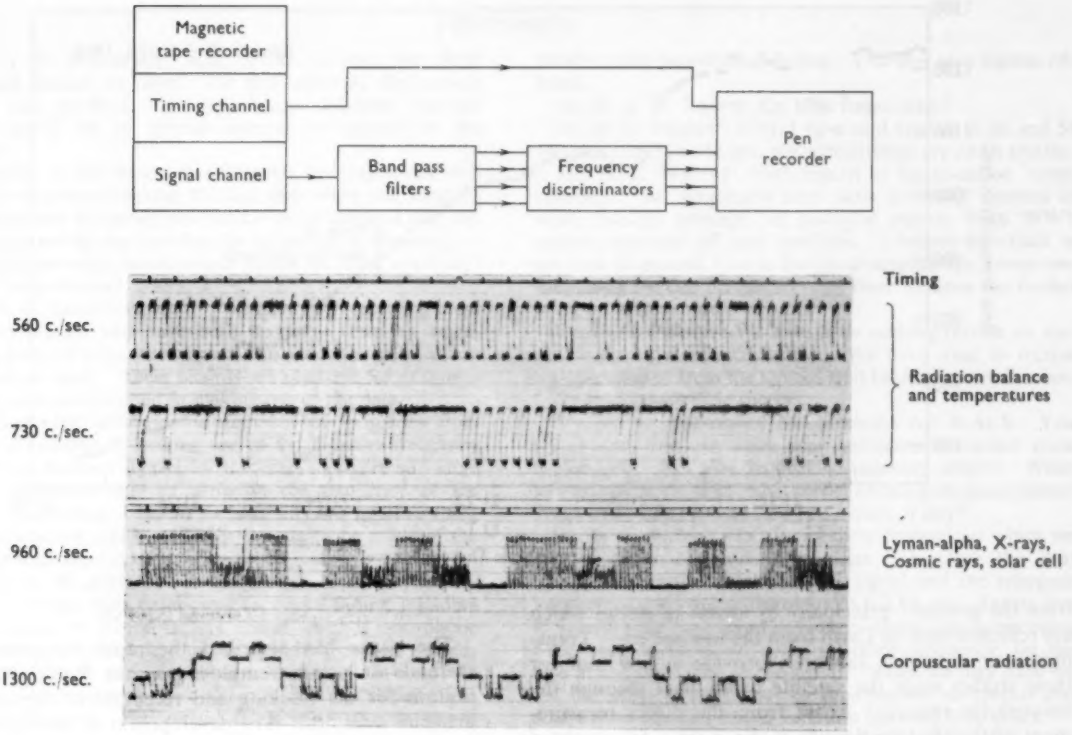

FIG. 8. Analysis of *Explorer VII* telemetry.

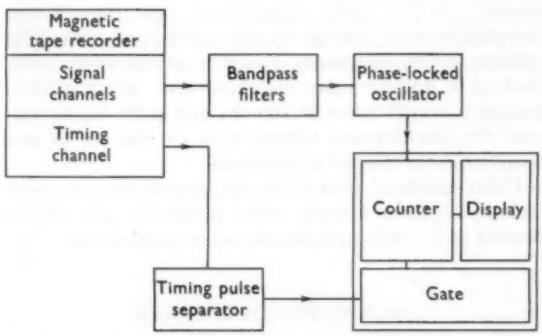

FIG. 9. Doppler frequency shift analysis.

recording and the play-back speeds of the tape. The accuracy of measurement is 1 c./sec.

A typical plot of the frequency shift against time on a 20 Mc./sec. signal is shown in Fig. 10. From this curve the time of nearest approach of the satellite to the receiving station is indicated by the point maximum slope. The speed and range of the satellite may also be calculated but unless due allowance is made for the curvature of the track, the relative movement of the Earth and drifts in the transmitter frequency, grave errors can arise. The deviations of the measured points from a smooth curve are due to ionospheric effects on the transmission path.

Observations of the Doppler frequency shift are of value in the study of radio wave propagation through the ionosphere and this is particularly so if they can be made simultaneously on two frequencies one of which is sufficiently high to be virtually unaffected by the ionosphere. One type of U.S.A. satellite, Transit, transmits phase-locked signals on frequencies of 54 and 324 Mc./sec. and equipment has been developed to measure directly the relative frequency shifts on the two signals. In this equipment the two reference signals are derived from the same crystal oscillator and the two beat frequency signals are brought, by multiplication or division, to a common nominal frequency before being finally mixed to produce the required difference frequency signal which is recorded directly on to a paper chart.

IV. THE USE OF SATELLITE OBSERVATIONS FOR RESEARCH PURPOSES

Radio propagation over long distances depends upon the ionosphere and much effort has been put into the study of its characteristics over the past four decades. Hitherto, however, the measurements have been made

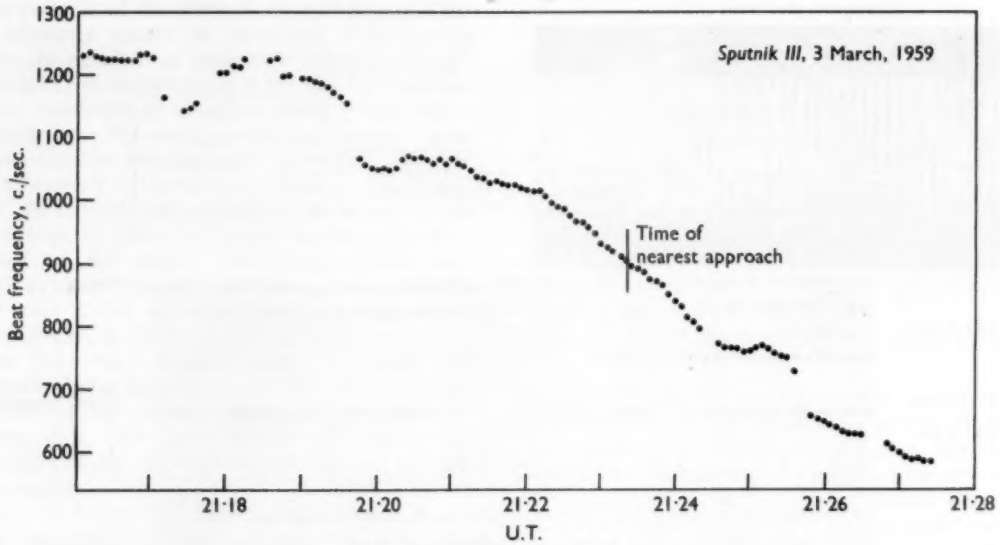

FIG. 10. Sample Doppler curve.

from the ground—principally by means of pulses which are reflected back to Earth from the ionosphere. Transmitters in satellites, however, provide a new tool for these studies since the satellite orbits pass through the ionospheric regions. Apart from the direct measurement of the electron density of the regions by means of instruments carried in the satellite, examination of the characteristics of the signals received on the ground yields valuable information on the medium through which they have passed.

Mention has already been made of errors in radio directional measurements due to the refraction of the waves by the ionosphere. These errors are greatest at the lower frequencies (20 Mc./sec.) and at low angles of elevation. If, therefore, sufficiently precise measurements of the angular deviation of the waves from the straight line path can be obtained, some deductions as to the characteristics of the ionosphere can be made.

Again a study of the difference between the observed Doppler frequency shift and that computed from a knowledge of the track and speed of the satellite, as has already been indicated in Section III.3, will yield data on the electron density of the ionosphere.

Another important characteristic of the radio wave reaching the ground is its polarization. If the satellite is emitting a linearly polarized wave, then, during its passage through the ionosphere its plane of polarization will be rotated. If a linearly polarized receiving aerial is used, the amplitude of the recorded signal will rise and fall in step with the rotation of the polarization during the satellite's transit. A study of the number of rotations and the rate of rotation allows deductions to be made of the electron density of the ionospheric regions through which the wave has travelled.

V. CONCLUSIONS

The paper has described the radio equipment and methods at present employed at the Radio Research Station for the tracking and reception of signals from artificial satellites. The development of the equipment has progressed as the needs have arisen and there has been continually the problem of keeping abreast of the latest developments in satellite instrumentation, particularly in the early stages when new transmission frequencies were being brought into use with little warning. The frequency position is, however, now tending to become more stabilized and advance information is usually given on any changes in the frequencies used for tracking and telemetry or on the use of new frequencies for special experiments.

Fuller details of some of the equipments and measuring techniques have already been published and papers dealing with other equipments are in preparation.

ACKNOWLEDGEMENTS

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DISCUSSION

Dr. A. P. WILLMORE,* B.Sc., Ph.D.: I have two quite unrelated queries to raise. The first concerns the records which you produce. Do you make available records which would be of special interest to groups in the country?

Secondly, is the reason that Doppler tracking is not well suited to accurate tracking the fact that when you measure frequency very accurately you need a lot of time and that this is complicated by the fact that the frequency is changing, so that more accurate measurement ceases to mean anything? Is that the problem?

Dr. B. G. PRESSEY (*in reply*): We have been receiving these telemetry signals and have been decoding them by transcribing them on to paper records, from which the information can easily be read. These records are available for examination by anyone interested in making use of the data.

Although the accurate measurement of frequency does present a problem in making use of the Doppler frequency shift of the received signals for tracking, there are still large errors, apparently due to drifts in the frequency of the satellite transmitters. So far there is only one satellite which has a sufficiently stable oscillator for use to be made of the Doppler shift for tracking purposes.

Mr. S. A. W. JOLIFFE†: In designing a satellite telemetry system a margin must be allowed for signal fading. Fading may be caused by several factors, one of which is ionospheric scintillation. As I understand you have recorded signals, from the Transit satellite, at frequencies of 54 and 324 Mc./sec.; can you state the order of amplitude variations at both frequencies? This would be of great interest to us, since we are considering satellite telemetry systems at frequencies of 136 and 400 Mc./sec.

Dr. B. G. PRESSEY: In the daytime, fading due to scintillation is small. The major fading observed is due to polarization rotation in the case of many satellites, but when circular polarization is used fading from this cause is also small. At night, however, the scintillations may be appreciable and comparable with polarization fading. I cannot give figures offhand.

Mr. S. A. W. JOLIFFE: On both frequencies?

Dr. B. G. PRESSEY: What I have said applies to 20 and 54 Mc./sec.; on 324 Mc./sec. the scintillations are much smaller.

Mr. A. T. WATTS‡: With regard to the so-called "silent satellites," the Americans have done a certain amount of work, mainly amateur, in receiving signals from WWV stations bounced off such satellites. I believe that back in the days of *Sputnik I* we in Britain attempted this, unsuccessfully using the Gee transmissions. Have we done any further work on it since then?

Dr. B. G. PRESSEY: We have done nothing further on that at the Radio Research Station. We have tried to receive signals reflected from the ionized trail behind the satellite but, I am afraid, with little success.

Mr. S. A. ANDREWS,§ M.I.Mech.E., A.F.R.Ae.S.: You report that you are using tape recorders to record some frequencies. Are you recording frequency direct? When you play back the tapes, what sort of accuracy do you achieve? What frequency variation do you expect, if any?

Dr. B. G. PRESSEY: In all cases, the frequencies which we are recording are audio-frequencies. They are the beat frequencies produced between the signal and the reference frequency, which are of the order of 1–2 kc./sec. Errors due to variations in tape speed have been eliminated by recording 1-sec. time markers, or some reference frequency, on the tape at the same time as the signal. When we play back we use the reference frequency or time marker to operate our analyser so that tape speed variation has very little effect.

Mr. S. A. ANDREWS: You chose three-eighths of a wavelength from the ground for your aerial placing. Is there any reason for that?

Dr. B. G. PRESSEY: This distance is chosen to obtain a suitable polar diagram for the aerials. It will give maximum indication at high angles of elevation with little pick-up in the horizontal direction.

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THE MEASUREMENT OF THE PERFORMANCE OF LIQUID PROPELLENT ROCKET ENGINES*

By A. W. T. MOTTRAM,† B.Sc., A.M.I.Mech.E.
(Communication from Bristol Siddeley Engines Ltd.)

ABSTRACT

The special requirements of instruments used for the development of liquid propellent rocket engines are reviewed and satisfactory techniques are enumerated. It is noted that high accuracy is only required in conditions favourable to the instruments. For the bulk of measurements, reliability is the prime criterion.

Suitable transducers and recording apparatus are now readily available, though this was not the case only a few years ago.

I. INTRODUCTION

THE history of rocket engine development since the war has perhaps been typical of that of a new engineering technique. In the early stages the amount of existing knowledge that could be directly applied to the field was small and the theoretical background was almost non-existent. Development proceeded therefore by a process of trial and error, with theoretical prediction replaced by the "informed guess." In time, however, a wealth of empirical information was built up which was correlated with other engineering knowledge. Finally, the stage has been reached when the designer can predict a "near miss" straight from the drawing board.

This process has both affected, and been affected by, the parallel development of rocket instrumentation. At first, the requirements were not stringent. It was sufficient in those days for a piece of hardware to be substantially intact after testing for the test to be considered a success. The thrust, or flow, or whatever it was, had to be in the right bracket, but performance played second fiddle to durability. The situation now is quite different. Rocket engines are in general reliable and controllable and the customer demands higher standards of precision and efficiency. These standards can only be proved by instruments of the highest quality, which are precise and possess a high order of reliability.

That these standards have been substantially achieved reflects great credit on the instrument engineers. They have not been achieved painlessly, however, and the development of engines has been hampered by the need for concurrent instrument development and the evolution of workable theories has been held up by the lack of precise data at a sufficiently early stage.

The author's company has developed since the war a comprehensive system of instruments for rocket engines. This system may well differ considerably from those developed by other rocket establishments. This is because we have been engaged in the development of rocket engines and the success of the programme has been judged by the performance of the end product—a rocket engine. It is not sufficient for an instrument to be precise or accurate or compact or cheap, however desirable these qualities may be. It is judged by this simple criterion—"Does its use facilitate the development of a reliable rocket engine to meet its specification?" Instrumentation for its own sake then is not tolerated.

It is to be expected that instrumentation for solid propellent rockets will be different from that for the liquid propellent engines that are within the author's experience. It is likely that the criterion of "instrumentation for development" will lead to similar solutions, but these are outside the scope of this paper.

It is concerned with the provision of instruments for the purpose of assisting the development of liquid propellent engines and the effect that this purpose has on the evolution of the system.

II. REQUIREMENTS OF AN INSTRUMENTATION SYSTEM

Before considering the requirements of an instrumentation system, it is appropriate to examine briefly the characteristics of the engine, and the use to which it will be put.

A liquid propellent rocket engine converts the chemical energy of the propellents into kinetic energy of the exhaust jet, the reaction of which exerts the thrust. This is achieved by the release of the chemical energy as heat in a high pressure combustion chamber, followed by expansion of the product gases through a convergent-divergent nozzle. The liquid propellents must be forced into the combustion chamber and this is achieved either by expulsion from a high pressure tank or by some kind of mechanical pumping apparatus. One or other of the propellents is usually circulated around the combustion chamber to cool it before being injected into the combustion zone. The pumping machinery is driven by a high speed impulse turbine driven by a small proportion

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† Research Engineer (Rockets), Bristol Siddeley Engines Ltd., P.O. Box 17, Coventry, Warwickshire.

of the main propellent flow. This short description does not exhaust the possibilities, but it is representative of the majority of engines and serves to illustrate the nature of the device to be tested.

The performance of a rocket engine in a vehicle is determined by three factors, specific impulse, mixture ratio and mass. Specific impulse, which may be defined as the impulse produced per unit mass of propellents, is a measure of the efficiency of the engine cycle. For all practical purposes, it is the only thing that matters, since the vehicle designer will accept serious penalties in weight in order to secure high specific impulse. Mixture ratio is important in that it determines the use made of the propellents with which the tanks are filled. If the mixture ratio is wrong, a surplus of one propellent will be left, which is so much mass carried to no purpose. Engine mass, as we have said, is of less importance, though rocket engines are lightweight machines by any other standards.

The natural consequence of these considerations is that the most important quantities to be measured are thrust and propellent flow, since from these measurements the specific impulse and mixture ratio are derived. Enormous amounts of care and trouble are cheerfully expended in improving the accuracy and reliability of these measurements. It is indeed fortunate that in the vast majority of cases they are made under quasi-steady state conditions. Fluctuations of thrust and flow there are, and they must often be studied, but if they are of such an amplitude as to seriously affect the measurements of average thrust and flow, they must be reduced for quite different reasons. It is also fortunate that the measurements are usually required to be integrated over a relatively long period. The most precise measurements, then, are made under favourable conditions. Information about thrust and flow fluctuations is, of course, essential. It is, however, required in order that remedial action may be taken to reduce their amplitude and consequently a much lower standard of accuracy is adequate.

The next group, which contains the bulk of measurements, is concerned with the detail behaviour of the engine. The vehicle designer is not concerned with this at all, provided that the engine gives the required overall performance. One may conclude that it is of little importance. For the vehicle designer this is true, but the engine designer sees things differently. He will not be satisfied with any less than a complete understanding of the processes going on in the engine. This understanding enables him to establish component and system reliability and speeds the diagnosis and correction of defects. Since these are the main objectives in a development programme, apart from performance, the measurements on which they are based are very important to the development engineer.

Most of these measurements are system pressures, plus a few flows and temperatures. The limits set on accuracy are less stringent than for overall performance measurement, but transient and fluctuating parameters must be recorded. The engineer is often more concerned with the relative timing of transients than with their amplitude. These transients are normally of low frequency and a response level to 50 c./sec. is adequate.

High-frequency transients also occur and their effect may be to cause rapid deterioration of engine components. They are, however, comparatively rare, at least within the author's experience, and high-frequency instruments are therefore needed for occasional use only. It is in any case extremely difficult to install suitable transducers in such a way that they do not interfere with the normal functioning of the engine. For this reason they are usually installed in a manner which makes it impossible to measure fluctuating amplitudes with any accuracy. Moreover, the equipment is more complicated and less reliable, so that the results are obtained at the expense of more trouble, which means more development time. In fact, the instrumentation engineer is often embarrassed by the cause of a transient being removed before he has succeeded in measuring it, often as the result of a modification based on an intuitive judgment by the development engineer.

We can now form a picture of a system of instruments for the development of a liquid propellent rocket engine. There will be highly developed techniques for precise measurement of thrust and propellent flow in quasi-steady state conditions. There will be a large body of instruments capable of recording system pressures, flows and temperatures to a lower degree of accuracy, up to a frequency in the region of 50 c./sec. There will be a small amount of equipment for recording high-frequency transients requiring only a low standard of accuracy.

III. RELIABILITY

This subject has been separated from the rest because of its special importance which can hardly be stressed too highly. It must be remembered that the object of a rocket engine development programme is to produce a thoroughly reliable rocket engine. To do this, the instrumentation must be an order more reliable than the engine. Time was when this was not difficult, but engines have now developed to the stage where they begin to approach absolute reliability and this imposes a harsh requirement on the instrument system. All too often one finds that instruments whose purpose is to show malfunctioning in the engine are in fact being checked themselves against the more reliable engine. This process of concurrent development of engine and instrument is most undesirable. It was imposed on the rocket industry in the early stages since suitable instruments did not exist. There is little justification for it now.

The inevitable conclusion to be drawn from this is that the most desirable characteristic of a measuring device is simplicity. Convincing arguments, backed by comprehensive statistical calculations, are often heard for the use of complex systems which offer a marginal improvement in operating convenience or overall cost.

These arguments are seldom borne out in practice and it is good practice to use the simplest method available—even at the expense of some accuracy. The system should be so arranged that it can be calibrated directly throughout without serious inconvenience. It is not sufficient to rely on an occasional transducer calibration coupled with more frequent calibrations of the recording system against an electrical standard. This is so for two reasons. Firstly, it is vital that incipient failure of any part of the system should be detected as soon as possible. The cost of running a rocket test facility is high. More seriously, the life of a rocket engine is measured in minutes or hours rather than days, so that the cost of an abortive test is much higher than the facility running costs might suggest. Secondly, the reliability of the system can only be proved by regular calibration showing consistent behaviour over a period of time.

Frequent calibrations of the whole instrument system also result in a less definable but extremely important commodity. The development engineer must have confidence in the reliability of his instruments. This can only be built up by favourable experience. He cannot be expected to make sure technical decisions if he is always afraid that what he thinks is a significant trend in engine behaviour will turn out, too frequently, to be a progressive deterioration in the thrust-measuring system. This leads to a test which should in my opinion be applied to all rocket instruments, in addition to the usual measurements of sensitivity, linearity, drift, etc. Put simply it is "Does the development engineer believe the results?" The answer should be a plain affirmative with allowance made for the need for occasional persuasion.

IV. MEASURING TECHNIQUES

Satisfactory techniques for rocket engine performance measurement are now available, but this has not always been the case. Ten years ago, the rocket industry represented the major part of the demand for this type of instrument. Consequently, the necessary transducers and recording gear were not available. Those engaged in engine development were forced to carry out parallel programmes of instrument development suited to their special needs, or else "make do" with apparatus that was hopelessly inadequate. Since then the field of application of this type of instrumentation has widened enormously owing to developments in atomic energy, process control and automation. Consequently a wide range of transducers and recording gear which are suitable for engine development is now available and there is no longer much need for rocket engineers to make their own instruments, except in special cases. The main difficulty is one of choice between systems when there is little to choose between them. Any attempt to compile a list of optimum techniques therefore relies on comparatively fine distinctions and marginal advantages. The list which follows is not to be regarded as exclusive. It is but a guide and is highly coloured by the author's experience.

1. Thrust

The best basic thrust measuring transducer is a rubber-bonded hydraulic capsule with a pressure transducer screwed directly into it. No other connexions should be made. In particular the addition of a Bourdon gauge for monitoring purposes is fatal. The pressure transducer should be of the unbonded wire strain gauge type.

Much more difficult than the provision of a satisfactory thrust transducer, is the problem of ensuring that the thrust generated by the engine is transmitted whole and entire to the measuring capsule. The engine must be mounted on a movable frame with negligible friction in the supports; this can only be ensured by the use of flexural hinges. Propellent feed pipes and other services must be connected in such a way that loads due to pipe stiffness, to pressurization, or to liquid flow momentum effects, do not produce significant components in the direction of the thrust axis. The most serious pitfalls occur when testing engines in the vertical attitude, since the weight of everything connected to the engine will make some contribution to the nett thrust. These problems account for nine-tenths of the troubles associated with thrust measurement and attention paid to them at an early stage will be repaid tenfold.

2. Flow

Of all the devices which have been investigated for the measurement of propellent flow, the free turbine flowmeter has been shown to be the best. It is linear, highly repeatable and has a fast response time. Its output is essentially digital and is in a convenient form for integration. A lot of work has gone into its development and the mechanical problems associated with the bearings have been solved.

3. Pressure

Wherever the application allows, Bourdon gauges should be used for pressure measurement. They are simple and reliable and will withstand a great deal of rough treatment. The results are immediately apparent, and when photographed correctly they produce records which can be read by unskilled personnel.

They have been heavily criticized in the past—often on unfair grounds. When it comes to developing rocket engines, however, they remain among the most useful instruments available to the engineer.

For general purpose recording work, bonded wire strain gauge pressure transducers are recommended. They are fairly robust and easily repaired when damaged, although not generally capable of high accuracy.

Higher accuracy is afforded by their unbonded strain gauge counterparts. These are now readily available and have the considerable advantage of high electrical

output. In my opinion they will shortly replace the bonded gauge in most applications.

4. Temperature

Temperatures in a rocket engine are either so low as to present no serious problems, or so high that their measurement is almost impossible except as a special laboratory investigation. The former are catered for quite adequately by thermocouples and the development engineer is usually happy to leave the latter severely alone.

5. Recording

For general purpose recording of system variables, direct writing pen recorders give adequate accuracy and frequency response with great operating convenience. The records are immediately available for correlation with the development engineer's subjective impressions of the test. Diagnosis of faults and remedial action are thereby expedited.

For more accurate recording of critical variables, notably thrust, recording mirror galvanometers have the merit of extreme simplicity coupled with high accuracy. They are sufficiently sensitive for direct connexion to the appropriate transducer. This results in a satisfyingly low occurrence of faults.

For the recording of fast transients and fluctuations beyond the response of mirror galvanometers, a simple cathode ray oscillograph and camera gives adequate accuracy.

The recording of flow rates presents a problem in frequency measurement. The maximum amount of information available from the transducer may be recorded by feeding the transducer output direct to a mirror galvanometer and subsequently digesting the record at one's leisure. For the general recording of system flows, however, simple electronic ratemeters feeding pen recorders are suitable. When precision measurements are required they are invariably required as average flow rates over a comparatively long period. Gated electronic counters with print-out facilities are ideal for this purpose.

It will be noted that with the exception of flow measurement, all records are recommended to be produced in analogue form. This is not intended as a slight on the many systems of digital data recording now under intensive development. It arises more out of the nature of the task than anything else. Continuous records on all channels are required since the event of interest may occur at any time during the test. An analogue record is required in any case to enable the development engineer to interpret the results. Quite often, little or no data reduction is required. When it is, adequate accuracy can be obtained from analogue records. When a large number of readings are required, semi-automatic trace-reading machinery associated with a digital computre can solve most problems. By and large, then, there is no pressing need for digital recording systems except in special cases.

The most important factors that weigh in favour of analogue recording, however, are its great simplicity and reliability proven over a long period of time. The introduction of digital recording will therefore be a slow process subject to the acid test of confidence on the part of the user.

V. Standards

The provision of adequate field standards for rocket instrumentation presents an extremely difficult problem, especially in the cases of sensitive thrust and flow measurements. The environment in a rocket test bed is not entirely favourable to any instrument, so that laboratory-type standards are not good enough. The standards used must be, therefore, at least as robust as the instruments themselves and capable of being removed when necessary to a safe place during testing. They must also be convenient to use, as frequent calibrations are needed to maintain reliability and they must, like the instruments, have the full confidence of the development engineer.

The methods, suggested below, of providing these standards offer a reasonable compromise between the conflicting requirements of accuracy on the one hand and convenience on the other.

1. Thrust

There are two methods which are satisfactory:

(*a*) Dead weights with a precision lever system.

(*b*) Rubber-bonded hydraulic capsule with precision Bourdon gauge.

These two methods differ in cost and flexibility, the second being superior in these aspects. Where the application justifies the cost of the first, it is undoubtedly more convenient in use.

2. Flow

Volumetric calibration using a specially designed tank with necks containing triggering devices at each end of the test section, is the best method for field use. The test volume can easily be checked to high standards. It has been suggested by some workers that gravimetric standards should be used. This is, I think, based on the definition of specific impulse in terms of mass flow. It must be recognized, however, that rocket vehicles are provided with tanks designed on a volume basis and that the engine is required to use the correct proportions of propellents by volume. The use of volumetric calibrating methods is therefore technically sound and is also less expensive and more convenient.

3. Pressure

This is catered for quite adequately by the conventional dead weight press and precision Bourdon gauge, the

latter being used when contamination of the piping must be avoided.

4. Temperature

Except in very special circumstances, mercury-in-glass thermometers or standard thermocouples with a precision potentiometer, are quite adequate.

VI. CONCLUSION

The science of measurement has now been brought to the pitch where there are no serious difficulties to be expected in the provision of adequate instrumentation systems for rocket engine development. The necessary techniques have been established in parallel with substantial improvements in the efficiency and reliability of the engines themselves. The combined effect of these processes has been to reduce the time required for engine development and to facilitate the production of reliable and efficient rocket engines. The prime function of the instrumentation system has therefore been substantially fulfilled.

ACKNOWLEDGEMENTS

The author's thanks are due to the management and staff of Bristol Siddeley Engines Ltd. who have made possible the writing of this paper and to the Ministry of Aviation who have given their support to developments in the rocket instrumentation field.

The views expressed herein are solely those of the author and do not purport to be shared by Bristol Siddeley Engines Ltd.

DISCUSSION

Mr. J. Underwood* (Fellow): Could the author give some idea of the order of accuracy he would expect in system pressure measurements, in particular in routine testing? He spoke of the relationship of accuracy and the type of test he has done and also the frequency response of the pressure transducers he used. But in the case of the normal routine testing to obtain the performance of an engine against something which has previously been developed, could he give some idea of the order of accuracy which will be necessary?

Mr. A. W. T. Mottram (*in reply*): For routine system pressure measurements in the development of rocket engines a routine accuracy of $\pm 1{\cdot}0\%$ would be quite adequate. The attainment of this degree of accuracy does not present unreasonable difficulty.

Dr. W. R. Beakley,† M.A., Ph.D.: Mr. Mottram has given us a lucid account of rocket instrumentation, which is a very difficult subject with which to deal. He is much more optimistic than I have previously known him to be. He knows as well as I that a very great deal of work has been done to bring rocket instrumentation to the present stage.

I feel that his optimism is due to his having been in on the development of the motor and the instruments simultaneously. They are now getting some extremely good results.

I should like to ask him whether he has yet started using liquid oxygen and encountering the flow measurement difficulties which come with it. If he has used it, or might in the near future, is he still optimistic about the effectiveness of the instrumentation?

Mr. A. W. T. Mottram: It may be that I am a little more optimistic than I have been in the past about rocket instrumentation, but I am optimistic about instruments used solely as aids to the development of rocket engines. The degree of my optimism may be estimated from this consideration: if I were given the task of laying down the instrumentation for the development of a rocket engine I would not expect any serious technical difficulties in the specification. The bulk of the necessary apparatus can be obtained from commercial sources which have as a rule no direct connection with rocket development.

Liquid oxygen certainly brings special problems. Dr. Beakley well knows that my association with liquid oxygen dates back several years and that I cannot speak from recent practical experience. In spite of the shortcomings of the instruments then available, we succeeded in developing technically successful engines using liquid oxygen, the design of which was extremely complicated. I think our main difficulties were associated with the provision of suitable calibration facilities.

I do not know which of the problems associated with flow measurement is in Dr. Beakley's mind. I would not expect any serious difficulty, though I should have to point out to the development engineer that the free turbine flowmeter measures volume flow and that this information is insufficient without simultaneous measurements of specific gravity as a function of temperature, vapour content and pressure.

Mr. Dennis Carton,§ A.F.R.Ae.S., M.A.R.S. (Fellow): The measurement of the performance of rocket engines is not so easy as Mr. Mottram has been trying to make out. I think this has happened because he spends quite a portion of his time talking to potential buyers and users. These people obviously have to be convinced that the rocket engine they are acquiring, in addition to its reliability, possesses a satisfactorily repeatable performance. This is a most necessary approach, but in fact the absolute accuracy of the performance information is not known.

Now a number of situations may exist where the accuracy available to Mr. Mottram is inadequate. For instance, inadequate performance of a rocket engine obviously affects the performance of the vehicle within which it is operating. This effect becomes increasingly more important as the size scale of the vehicle's effort increases. Therefore above some point on the engine size scale, absolute performance becomes increasingly important and must be known with increasing accuracy.

Or consider the occasion when it is required to improve the performance of a rocket engine by the summation of small improvements to the performance of its components. Obviously each separate small improvement will require a much increased accuracy of comparative performance measurement.

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§ Department of Aircraft Propulsion, College of Aeronautics, Cranfield, Bletchley, Buckinghamshire.

I am not pulling back the curtain in order to upset anyone in the rocket industry. Nor am I normally concerned with a measure of "brochuremanship." Nevertheless, I am perturbed that the impression left by the paper is that there is no longer any problem involved in satisfactorily measuring rocket engine performance. This is a narrow and over-simplified view.

Mr. A. W. T. MOTTRAM: I think that Mr. Carton has missed the point of my lecture, which was to discuss rocket instrumentation as an aid to engine development. Most of his comments are not therefore particularly relevant although the issues raised are of considerable interest.

It would be a useful exercise to study them more fully, for important philosophical considerations arise at an early stage in any discussion of absolute measurements. This study should lead to conclusions the implications of which could be assessed in relation to such topics as vehicle size and the effect of small improvements.

The results may surprise Mr. Carton as much as they would interest me.

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AN EQUIPMENT FOR PROCESSING TIME-MULTIPLEXED TELEMETRY DATA*

By D. J. McLAUCHLAN, B.Sc., Grad. Inst. P., M.I.R.E.† and T. T. WALTERS†

ABSTRACT

This paper describes an equipment for the reduction of Time-Multiplexed telemetry data. This equipment accepts a magnetic tape input and, after analogue processing, produces outputs in the form of film and punched cards.

I. INTRODUCTION

ANY satellite programme or extensive programme of sounding rockets will encounter a data reduction problem. Every experiment will result in hundreds of thousands, or millions, of measurements. These represent a volume of data which cannot be handled by manual methods.

The TIMTAPE equipment described in this paper is built to overcome the data reduction problem, which was in this case encountered in the development of a guided weapon. This equipment (Fig 1) has been operational for a considerable time. Its main use has been for reduction of data from test missile firings, but in addition it has been used to process some Skylark data.

Further relevance to the space field is given by the fact that TIMTAPE might require only minor modifications to enable it to reduce data obtained from British experiments in space.

1. PURPOSE OF THE EQUIPMENT

The purpose of the equipment is to convert data from a frequency modulated form on magnetic tape to punched cards and film records. During this process the data undergoes certain processes which can be performed conveniently in analogue form rather than in a complex digital computer.

2. INPUT

The input of the equipment is a magnetic tape derived from the well-known Royal Aircraft Establishment twenty-four-channel telemetry system. This is a time-division multiplex system, each of whose twenty-four inputs is sampled 100 times/sec. The output of the sampling switch is used to frequency modulate a sub-carrier oscillator, the frequency of which varies according to the magnitude of the input quantity. The output of this oscillator is used to amplitude modulate a radio frequency carrier.

One of the twenty-four channels is used for synchronization. Its frequency is fixed and outside the normal information band.

A second channel is used for transmission of calibration signals. Its input is switched at slow speed between a number of fixed known levels. This switching is asynchronous with the high-speed switch.

After reception, the sub-carrier signal is frequency transposed and tape recorded. Multi-track tape machines are employed and time reference signals are

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† Bristol Aircraft Ltd., Filton House, Bristol.

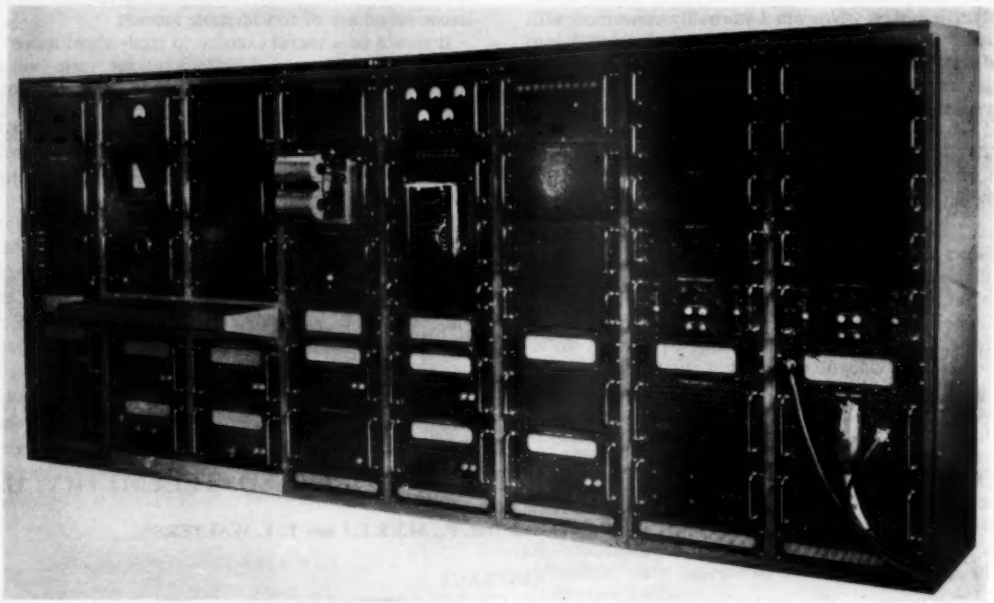

FIG. 1. General view of the TIMTAPE equipment.

recorded on a second track. The resulting tape is the input to the data-processing equipment described in this paper.

3. OUTPUT

The main requirement is for the production of punched cards for feeding into English Electric D.E.U.C.E. computers at Bristol Aircraft Ltd. The data punched on the cards are linear, calibrated and punched together with their associated time values. The linearization and calibration processes are performed in the TIMTAPE equipment. Analogue outputs are available for both processed and unprocessed data. These are used for making film records. Punched paper tape will soon be available as an alternative output.

4. PROCESSING FUNCTIONS

The equipment performs the following operations:

(1) The separation of individual time multiplex data and calibration channels.

(2) Interpretation of the data relative to the calibration levels.

(3) Calibration of the measurements which, in general, are not linear.

(4) Analogue to digital conversion of the data.

(5) Production of punched cards containing the linearized calibrated data and their associated time values.

(6) Photographic production of analogue records.

II. OUTLINE OF THE EQUIPMENT

A block diagram of the equipment is shown in Fig. 2.

The input tape is replayed at one-fifth of recording speed so that the sampling rate for any channel is 20 points/sec. This speed is dictated by the maximum rate at which the card punch can handle processed information. The sub-carrier frequencies at the chosen replay speed are in the range 6–14 kc./sec. The magnetic tape is replayed and the output fed to a demodulator. A stepped voltage wave form known as a voltage histogram is produced (Fig. 3).

Synchronization pulses are extracted from the histogram and used to trigger a saw-tooth wave form. The saw-tooth is used to produce strobing pulses which are employed to demultiplex individual data channels from the histogram. A further stage of synchronization separation and strobing is used to separate the calibration levels.

Data samples and calibration levels are fed to an analogue-to-digital converter. This unit performs compensation for system drift and transducer calibration. The value of each data sample is compared with calibration levels and the result linearized and digitized. The output is in parallel and is an eight-digit binary number. This is associated with its time value expressed as a twenty-digit binary number of milliseconds from vehicle launch.

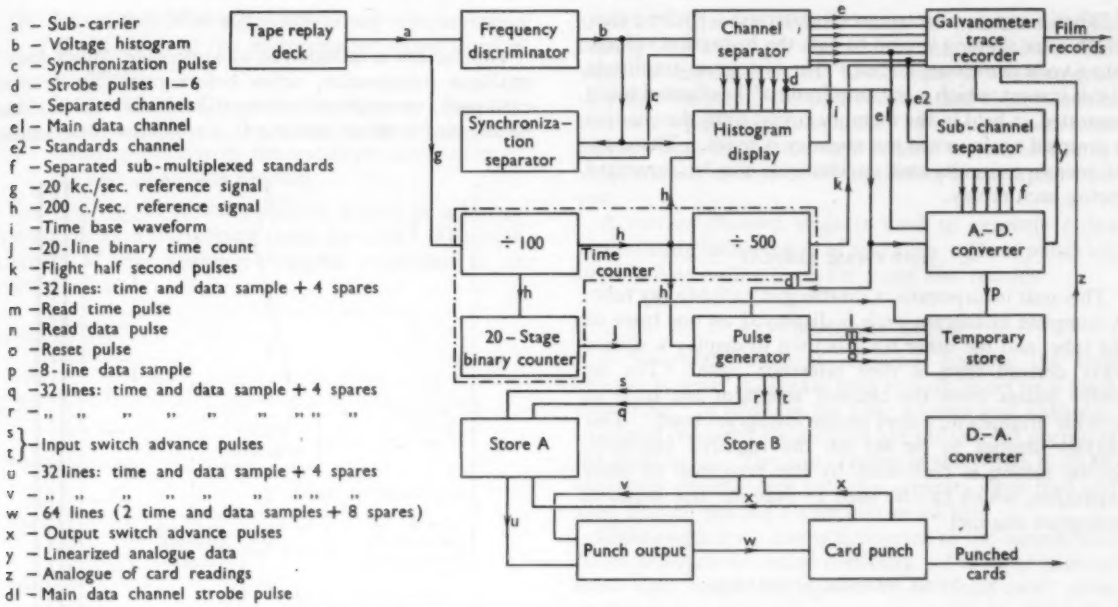
a – Sub-carrier
b – Voltage histogram
c – Synchronization pulse
d – Strobe pulses 1—6
e – Separated channels
e1 – Main data channel
e2 – Standards channel
f – Separated sub-multiplexed standards
g – 20 kc./sec. reference signal
h – 200 c./sec. reference signal
i – Time base waveform
j – 20-line binary time count
k – Flight half second pulses
l – 32 lines: time and data sample + 4 spares
m – Read time pulse
n – Read data pulse
o – Reset pulse
p – 8-line data sample
q – 32 lines: time and data sample + 4 spares
r – " " " " " " " " "
s, t – Input switch advance pulses
u – 32 lines: time and data sample + 4 spares
v – " " " " " " " " "
w – 64 lines (2 time and data samples + 8 spares)
x – Output switch advance pulses
y – Linearized analogue data
z – Analogue of card readings
d1 – Main data channel strobe pulse
Tape replay deck
Frequency discriminator
Channel separator
Galvanometer trace recorder
Film records
Synchroniza-tion separator
Histogram display
Sub-channel separator
÷ 100
Time counter
÷ 500
A.–D. converter
20 – Stage binary counter
Pulse generator
Temporary store
Store A
Store B
D.–A. converter
Punch output
Card punch
Punched cards

FIG. 2. Block diagram of the TIMTAPE equipment.

The card punch speed and the tape replay speed are not directly compatible. Compatibility is achieved by the use of a store for the data and time samples.

III. DESCRIPTION OF UNITS

1. FREQUENCY DISCRIMINATOR

The frequency discriminator produces a voltage output proportional to input frequency and is linear to within 0·25% of full scale deflection. The voltage histogram produced is used as an input to three other units, namely the synchronization separator, histogram display and channel separator.

2. SYNCHRONIZATION SEPARATOR

The synchronization separator is basically an amplitude-discriminating device responding only to the synchronization pulse. Various additional features enable this unit to produce usable synchronization pulses during periods of low signal strength, tape drop-out, etc.

3. CHANNEL SEPARATOR

Synchronization pulses are employed to generate linear saw-tooth wave forms. The amplitude of the saw-tooth at any instant is a measure of the fraction of the histogram cycle which has elapsed. A given saw-tooth amplitude therefore corresponds to the occurrence of a particular channel. The saw-tooth is used as a common input signal to a group of six voltage comparator circuits. The second input to each comparator is a d.c. voltage which can be varied between zero and the peak amplitude of the saw-tooth. The comparator circuit is triggered when the two voltage inputs are identical. A comparator can be made to trigger at any point in the histogram cycle, that is, on any desired channel, by adjustment of its d.c. input voltage.

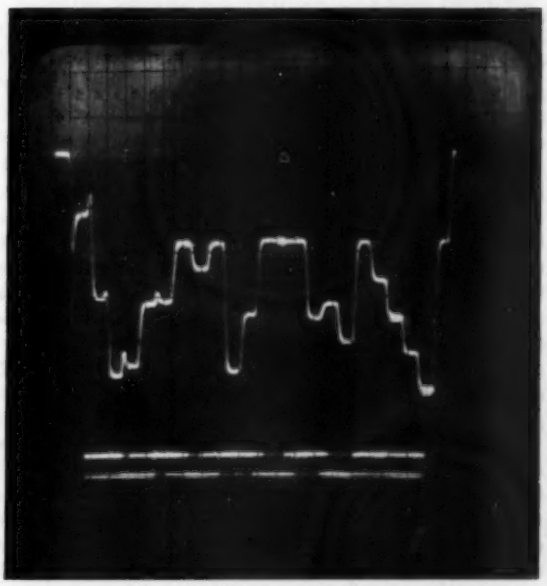

FIG. 3. Histogram sample.

When a comparator triggers it generates a strobe pulse, which after shaping is used to gate the histogram voltage into a voltage memory circuit. The histogram amplitude at this instant, which is the amplitude of the channel being separated, is held in the memory circuit until the channel is sampled again, when the memory is re-set. There are six memory circuits and six channels can be separated during each replay.

4. Histogram Display

This unit incorporates a double gun cathode ray tube. A complete histogram cycle is displayed on one trace of the tube, and the other trace is used to display a square wave derived from a time reference signal. The six strobe pulses from the channel separator are used to provide brightening pulses on the histogram trace. This enables strobes to be set on the required channels. Strobe setting is facilitated by the provision of trace expansion, which can be used to examine any required histogram channel.

5. Sub-Channel Separator

Continuous versions of the calibration signals are employed in the analogue-to-digital converter. Since calibration signals are switched at low speed on to one telemetry channel, a further set of strobes and voltage memory circuits is required. In addition, since the low-speed switching is not synchronous with the 100 c./sec. switch, another synchronization separation is necessary. These functions are performed in the sub-channel separator.

Synchronization is achieved by a pattern recognition circuit, the calibration levels being transmitted in a standard order. Five levels are employed, and five voltages roughly equal to the calibration levels are generated artificially in the unit. A coincidence detector is fed by the incoming calibration signal and by the pole of an electrically stepped switch, whose inputs are the artificially produced calibration levels. These artificial levels are sampled by the stepped switch in the same order that the calibrations are transmitted. Coincidence between the two signals produces a pulse which steps the switch to its next position. When the calibration signal changes to its next value, coincidence is restored and the switch again steps. Thus, if the standard levels arrive correctly the stepped switch is driven in synchronism with the calibration signal. When all five calibration levels have occurred the stepped switch generates a synchronization pulse.

The synchronization pulses thus generated are used to operate a strobing system analogous to that described for the channel separator, except that it is largely electromechanical in operation. The net result is that the calibration levels are presented as five continuous signals, re-set each time that the unit recognizes the pre-set pattern of five levels in the incoming signal.

6. Camera Recording

This facility is included so as to provide "quick look" analogue information, either before punching detailed card packs or when the information on any channel can be assessed without recourse to a computer programme.

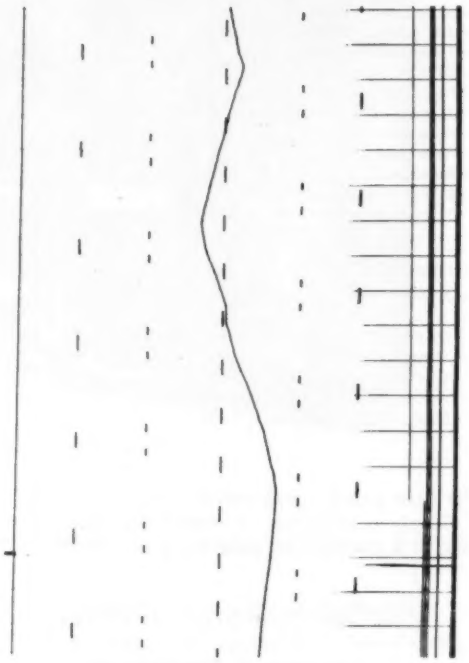

Fig. 4. Specimen film record.

The records are produced on 6-in. wide sensitized paper, and all six strobed-out channels can be recorded at once. A specimen film record is shown in Fig. 4.

Digital-to-analogue conversion facilities are included in two places:

(*a*) in the analogue-to-digital converter, so that linearized gain- and level-corrected analogue records can be produced on the paper film.

(*b*) at the output of the card punch "read" brushes, so that a pack of cards can be checked by use of the camera recorder.

7. Analogue-to-Digital Converter

The analogue-to-digital converter performs three distinct functions:

(1) Determination of the value of the incoming data sample relative to a scale derived from the calibration levels. Since these calibration levels have been subjected to the same drifts in gain and level as the data, the result of this determination should be independent of such drifts.

(2) Production of an eight-digit binary representation of the result of the determination carried out in (1) above.

(3) Introduction of a non-linearity into the conversion, which is the complement of the non-linearity evident in the pre-flight calibration of the particular data channel.

Thus the output of the converter should be a binary representation of the original input quantity. The basic principle of the analogue-to-digital converter is as follows.

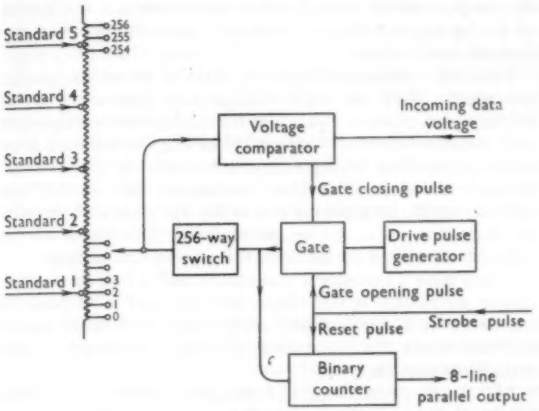

FIG. 5.

A resistor chain containing 256 steps has a current maintained in it such that the voltage across its ends is a little greater than that between the two outer calibration levels.

The calibration levels, from low-impedance output stages in the sub-channel separator, are impressed on the resistor chain at points corresponding to the distribution of the levels through the data range. A 256-way electronic switch is arranged to step progressively from one end of this chain to the other. A generator supplies pulses to drive this switch via a gate circuit. As well as advancing the switch the pulses from the gate output operate an eight-stage binary counter. A comparator is employed to compare the incoming data voltage with voltages sampled by the stepping switch.

An incoming strobe pulse resets the switch and binary counter to zero and opens the gate allowing pulses to advance the 256-way switch and operate the counter. When the comparator detects a voltage equal to the incoming data voltage it produces a pulse which closes the gate and prevents further pulses from advancing the switch or the counter. The counter output thus contains a binary representation of the data value relative to the calibration levels.

8. Time Counter

The time reference signal is recorded on one track of the magnetic tape, and on replay the output from this track is frequency divided so as to produce a signal having one cycle per millisecond of real time. This signal is displayed on the lower trace of the histogram display tube, and is fed to a twenty-stage binary counter and to the pulse generator unit. In most cases an event marker recorded on the tape is used to set the twenty-stage counter to zero at the beginning of each play-back run.

A further division stage is used to generate pulses representing half-seconds of real time. These pulses are displayed as ordinates on the paper film records.

9. Temporary Store

A temporary store is required, because the time counter is never stationary long enough to set up a main store row. In addition the time counter and analogue-to-digital converter outputs are not suitable for operating the main store. The unit consists of thirty-two bi-stable transistor circuits, each having a separate input feed and gate, and all sharing a common re-set line.

Eight stages have inputs connected to the output lines of the analogue-to-digital converter. The input gates of these eight stages are opened by a "read data" pulse produced by delaying the strobe pulse in the pulse generator for a time sufficient to allow the analogue-to-digital converter to operate.

Twenty stages have inputs connected to the output lines from the twenty-stage binary counter. The input gates of these stages are opened by a "read time" pulse produced in the pulse generator from the strobe pulse and the divided time reference signal, so that these stages are set up in the first static reading of the counter after the appearance of the strobe pulse.

After the temporary store stages have been set up for a time long enough to allow the appropriate relays in the main store to operate, a re-set pulse, again derived by delaying the strobe pulse, is used to return all the stages to zero. There are at the moment four spare stages.

10. Main Store

The primary output of TIMTAPE is an eighty-column twelve-row card, sixty-four columns of which are employed. Two statements are recorded on each row of the card, each one consisting of an eight-digit data sample and a twenty-digit time sample. The remaining positions are spare.

The main store is in two halves, each of which stores 32×12 digits. Each half consists of a matrix of twelve rows of thirty-two relays. Data samples from the temporary store are fed alternately to the two halves of the main store. This is accomplished by a set of change-over relays. The set of thirty-two outputs of the temporary store is connected in turn to the inputs of the main store rows by means of a thirty-two-pole twelve-way motorized switch.

Outputs from the stores are read in parallel by another set of motorized switches. The output consists of sixty-

four lines, each of which can take one of two voltage levels according to the state of the relay stores. These sixty-four outputs are fed to the card punch. Each store row is cleared when its output has been fed to the punch.

IV. CONCLUSIONS

TIMTAPE has been in regular use, in its present form, for over a year. During this time, it has proved reliable and accurate results have been obtained consistently.

TIMTAPE is designed specifically for use with one telemetry system. However, it is likely that the equipment will be capable, without extensive modification, of reducing data from other telemetry systems which are coming into prominence.

ACKNOWLEDGEMENTS

The authors wish to thank Bristol Aircraft Ltd. for its encouragement in the preparation of this paper. Thanks are also due to those members of its staff who have worked on the development of the equipment, in particular Mr. J. H. Russell.

DISCUSSION

Dr. A. P. WILLMORE,* B.Sc., Ph.D.: We have heard of this very simple and flexible use of the saw tooth to split up the time for the individual channels. This obviously depends on maintaining voltage levels accurately. What is the maximum number of channels that the authors feel they could cope with in this way before getting into trouble with voltage drifts?

Mr. T. T. WALTERS (*in reply*): The maximum amplitude of each time-base excursion is held and used as a d.c. feed to the comparator circuits, so that if the time-multiplexing switch speeds up or slows down, the strobe pulse for, say, channel 12, will always occur just before the point half-way through the time-base sweep.

Dr. A. P. WILLMORE: You have overcome the difficulties of a varying switch speed by that method?

Mr. T. T. WALTERS: I am not sure of the maximum number of channels which could be strobed out over any given sweep, but we have used a forty-eight-segment switch in place of the normal twenty-four-segment one and obtained satisfactory results. I think that the limit would probably be about 100 segments for reliable operation.

Mr. G. A. WAPLING†: I am greatly interested in this problem of using non-linear input to data handling systems, but I was unable to follow the lecturer's explanation of how this is done. Probably that is because we are nearing the end of the day. Can we persuade him to draw a block diagram of it? Could he explain the significance of using 256 steps on the switch?

Mr. D. J. MCLAUCHLAN (*in reply*): The 256 steps are concerned with the accuracy which we expect from the device. The overall accuracy of the telemetry system which we are using is normally 2 or 3%, and if we reckon on losing 0·5% we are accurate enough. I am sorry that Mr. Wapling did not follow my explanation, but we were asked to hurry.

Mr. T. T. WALTERS: I will draw a block diagram (Fig. 5). Standard voltages are impressed on the resistor chain. I have shown five. That is the use of the five sub-multiplex standards which you saw on the film record. This represents an electronic switch which can set up 256 steps in the resistor chain. The operation of the strobe pulse resets the counter to zero and resets the electronic switch to the bottom of the chain, and then initiates the new sweep. There is a pulse generator which is continuously feeding pulses via the gate to advance the 256-pole switch and also to feed the eight-digit channel counter. Once you have opened the gate in this way, the 256-pole switch starts to move up the chain. If it moves up all the way it will take 256 steps, which will fill the eight-digit channel counter.

When the voltage picked off the chain by the switch reaches coincidence with the data voltage you generate a pulse barrier which closes the gate and the reading held on the eight digit counter represents the number of steps which have been taken up the chain to reach coincidence with the data voltage. If the transmitter sub-carrier oscillators drift or the tape recorders drift, or anything else drifts, the standards drift by the same amount as the incoming data. The answer on the counter will always be the same for a given data voltage.

If you have a non-linear transducer calibration or the sub-carrier modulator is non-linear, all you need is to plug the standards in a peculiar way rather than at equally spaced intervals along the chain, and you have corrected for the transducer non-linearity.

Mr. S. A. ANDREWS,§ M.I.Mech.E., A.F.R.Ae.S.: Does this bring the accuracy conversion to 256, if you can put in the sweep?

Mr. T. T. WALTERS: As described, the equipment uses a four-straight-line approximations to the calibration curve. In practice, auxiliary standard levels are created above, between, and below the five real standard levels by interpolation from them. This creates an eleven-straight-line approximation to the true curve, which gives an accuracy of conversion of about one part in 256 with the type of calibration curve obtained in practice.

Mr. P. A. E. STEWART, A.R.Ae.S., F.R.A.S. (Fellow): How long would it be from the reception of the telemetered signal to the time that it would be available for use by a development engineer to sort out what was wrong with the missile?

Mr. T. T. WALTERS: It depends on what the development engineer wants. If he is content with a quick look at the analogue records, at matters in which he is interested, at a particular pressure variation during a test, for example, then this could be obtained for him—up to six such pressure variations—displayed on a piece of paper within ½ hr. of receiving the tape in the processing station. Many of the parameters with which we deal are used as variables in equations which are later processed by the digital computer. To reduce all twenty-four channels to punched card form to feed the computer usually takes between half-a-day and a day.

A MEMBER: Would the lecturer briefly review the punched card data-reading equipment which is used in conjunction

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† Drayton-Southern Ltd., West Drayton, Middlesex.

‡ Electro-Dynamics Dept., The de Havilland Engine Co. Ltd., Stag Lane, Edgware, Middlesex.

§ Astronautics Division, Advanced Projects Group, Hawker Siddeley Aviation Ltd., Kingston-upon-Thames, Surrey.

with this system? I am thinking of this as a practical problem, in a satellite.

Mr. T. T. WALTERS: I am not sure what information you want.

A MEMBER: In practice, what amount of equipment is needed to handle the punched card records, to study the satellite performance and to use the data obtained from it? What do you need to read it?

Mr. T. T. WALTERS: The reason for using punched cards is that the information is required as the input to a digital computer which will only accept data in this form.

A MEMBER: The basic features are the film records?

Mr. T. T. WALTERS: The basis is the eight-digit binary record or the analogue of this binary record. We would normally go through the binary conversion stage of this equipment beforehand. In the binary conversion stage we do the correction for drifts and non-linearities. For the kind of performance you have in mind you would be content with analogue graphs.

A MEMBER: They would be satisfied with that form?

Mr. T. T. WALTERS: We have a model running of a digital plotter which would accept the eight-line binary output and plot directly on graph paper as an additional record. I think that this would be most useful.

A MEMBER: In fact, there would be a time series representation?

Mr. T. T. WALTERS: Yes.

Dr. W. R. BEAKLEY,* M.A., Ph.D.: For some time we have been using analogue recording equipment for the static testing of rocket motors, mainly the reflecting galvanometer type, and we have been taking results from those by means of trace readers. The accuracy obtainable is about 1%, with a better accuracy if you are prepared to spend an extremely long time in data reduction. The answer is to automate the data reduction. That is best done by a digital computer, and you do best to start with digits at the beginning. We record mainly pressures and thrust, with some temperatures.

We have available the strain gauge type of gauge measurements and our problem is to digitize the analogue output from those transducers. This we do at an overall rate of 1000 times a second, giving the possibility of eight channels, because of time-multiplexing each 100 times a second, together with two extra channels, one for zero correction and one for sensitivity correction. It is all put on magnetic tape, with sixteen tracks on one tape. Later, a computer puts in all corrections and non-linearities and such like.

We digitize with a resolution of one part in 2000, although in general we use only 1000 of those digits, to give a precision of 0·1%. We are fully prepared to let the equipment drift in zero or sensitivity over quite a wide part of the scale so that a minimum of setting up has to be done by the operator on the site.

We have a small, simple, tape deck, sixteen tracks on a 1-in. tape, running a 15 in./sec. and with a packing density of 66 bits/in. As you can see, things like flutter and constancy of tape speed do not matter because we have so much in hand. It is very reliable.

We have our own small digital computer which performs exactly the normal function of a digital computer, but it has about a quarter the complexity of the straightforward digital computer, mainly because of the question of storage space. We need to store only twenty words, each of twenty-two binary digits; we can add and subtract and multiply and do all the things that the normal digital computer can do. We can determine pretty well what we like.

The answers come out in a graph plotter which we have specially designed and which will plot ten points—in future it may plot twenty—per second, with an accuracy of one part in 500.

The system is just coming into use and at the moment we are achieving results of perhaps a 0·25% accuracy. A little more development should bring us into the region of 0·1% accuracy.

Mr. S. A. ANDREWS: I should like to express my surprise that you are getting these accuracies, presumably using transducers—even strain gauge transducers. You are lucky to get an accuracy of 0·25%. If you correct for the fairly drastic temperature variations, I think it is astounding that the overall system will give you an accuracy better than 1%.

Dr. W. R. BEAKLEY: You must remember in recording the performance of rocket motors that 10 or 20 sec. is the normal firing time and that 3 min. is perhaps the outside limit. If you simply calibrate immediately before the firing, all the drifts are negligible in the very short space of time over which you work.

CONCLUSION

The Chairman, Mr. G. C. ELTENTON, B.A., F.Inst.P., F.Inst.Pet. (President, Society of Instrument Technology) concluded the proceedings by thanking all the authors for the hard work which they had put into preparing their papers (sometimes at the cost of interference with their holidays), and for coming to present them. He asked those present to join with him in thanking them and the organizers of the symposium.

A vote of thanks was carried by acclamation. The proceedings then terminated.

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†† Ministry of Aviation, Rocket Propulsion Establishment, Westcott, Near Aylesbury, Buckinghamshire.

CORRESPONDENCE

(In these letters to the Editor, some passages have necessarily been omitted)

Relativity and Space Travel

SIR,

Mr. Herman[1] has not met my point at all. Let me give it a slightly different form. I consider only what happens when M reaches α Centauri (R') and reverses, and I will show that Mr. Herman's account involves an impossibility, no matter how M leaves and arrives at the Earth.

Let this be the course of affairs. M passes R' at uniform velocity, and compares his reading with that of R'. Immediately afterwards he decelerates, quickly comes to rest and reverses, reaching his previous uniform speed just before passing R' again at that speed, and again compares his reading with that of R'.

That is a possible experiment: let us consider Mr. Herman's account of it on the two assumptions: (*a*) M moves, R and R' rest; (*b*) M rests, R and R' move.

(*a*) At the first coincidence (E_1), $R' - M = t$, say; the (positive) value of t may depend on the circumstances of M's setting out from R; it is quite immaterial. At the second coincidence (E_2), $R' - M = t$, except for a possible negligible effect of the acceleration.

(*b*) At E_1, $R' - M = -t$. At E_2, $R' - M = R - M = A - t$, where A is approximately $4t$, and may be very large.

Now the experiment can give only one result: which is it? Whichever it is, it will make an absolute distinction between the two cases, *i.e.*, between the ascription of the motion to R and to M. But the whole purpose of Mr. Herman's argument is to show that this distinction is not observable because on both assumptions M will be slow compared with R when M returns to R. He has not realized that, in order to avoid this evidence of the distinction he has necessarily provided equally good evidence in the comparison of M with R'.

The crux of the matter is that these "effects" of motion are all purely mental: they affect, not clock readings, but *the times at which the clocks have those readings*. A clock is slow or fast if its reading at an event is behind or ahead of the time of the event, and you can vary the time, but not the reading, by mentally changing your co-ordinate system.

In all *legitimate* applications of the "contraction" and "time dilatation" it is impossible by any experiment to tell whether the supposed effect has occurred or not, because it is essentially unobservable. In the Michelson-Morley experiment, for instance, if the Earth is at rest the two arms are equal in length; if the Earth is moving, one arm is contracted. But no possible experiment can tell you whether the arm is contracted or not, so you can hold which view you like without affecting any possible *observation*. That is not so in this case. The experiment I have described will, if Mr. Herman is right, tell you whether it is M or R' which has moved. Hence, if he is right, the principle of relativity is wrong, and it is precisely from that principle that he professes to obtain his result.

I hope that Mr. Herman will tell us which values the experiment should give for $R' - M$ at the events E_1 and E_2, and then explain what significance is to be attached to the other values, but I confess that the hope is a faint one. I have become only too accustomed, in this controversy, to asking such questions and receiving no answers, and then having to do it all over again for someone else who similarly relapses into silence.

HERBERT DINGLE.

104 Downs Court Road,
Purley, Surrey.
14 *June*, 1960.

REFERENCE

1. R. Herman, *J.B.I.S.*, 1959–60, **17**, 216.

SIR,

I do not dispute the fact that the equations given in Professor Dingle's letter are inconsistent, but they do not correspond to my account[1,2] of the space travel experiment. I can only conclude that Professor Dingle has misread or misunderstood my previous letter[2] (see second paragraph), so I give a more detailed account below. In this I state explicitly the reading of each clock with respect to each frame of reference at each of the significant events.

Let E_0 be the event of M's separation from R and E_0' the event of M switching off the rocket engine after the first period of operation. Let E_1 and E_2 be the events of first and second coincidence with R' as defined by Professor Dingle. Finally, on the return journey let M pass R with uniform velocity at E_3 and then come to rest on R at E_4. It is assumed that the time intervals separating the pairs of events E_0 and E_0', E_1 and E_2, E_3 and E_4, are arbitrarily small on M's clock, and that all clocks are zeroed at E_0.

With respect to R's frame of reference no significant change in the clocks readings occurs between E_0 and E_0', *i.e.*, at E_0', $R = R' = M = 0$. The interval between E_0' and E_1 is assumed to have a duration T and during this interval M's clock runs slow by a factor $\alpha = (1 - v^2/c^2)^{\frac{1}{2}}$. Hence at E_1, $R = R' = T$, $M = \alpha T$. These equations apply also at E_2. The interval between E_2 and E_3 has a duration T, during which M's clock again runs slow by the factor α. Since no significant

change in the clock readings occurs between E_3 and E_4 we have at each of these events $R = R' = 2T$, $M = 2\alpha T$.

If the calculations are made with respect to M's co-ordinate system, then the reading on R' is advanced by v^2T/c^2 between E_0 and E_0'. This is due to the large difference in gravitational potential which exists between the points where R' and M are situated, while the rocket engine is in operation. Hence at E_0', $R = M = 0$ and $R' = v^2T/c^2$. Subsequently, and until E_1, R and R' run slow by the factor α, the time interval between E_0' and E_1 by M's clock being αT. Therefore at E_1, $M = \alpha T$, $R = \alpha^2 T$, $R' = v^2T/c^2 + \alpha^2 T = T$. Between E_1 and E_2, R is advanced by $2v^2T/c^2$ due to the second appearance of the gravitational field, so that at E_2, $M = \alpha T$, $R = \alpha^2 T + 2v^2T/c^2 = (1 + v^2/c^2)T$ and $R' = T$. The interval separating E_2 and E_3 has a duration αT on M's clock during which R and R' once more run slow by the factor α. Thus at E_3, $M = 2\alpha T$, $R = (1 + v^2/c^2)T + \alpha^2 T = 2T$, $R' = T + \alpha^2 T = (2 - v^2/c^2)T$. Finally, between E_3 and E_4, R' is advanced by v^2T/c^2 because of the third occurrence of the field, giving at E_4, $M = 2\alpha T$, and $R = R' = 2T$.

It will be seen from the above equations that no discrepancy exists between the observers with regard to the reading on any clock at any event whose position coincides with that of the clock being considered. This is not necessarily the case, however, when the clock and the event in question are spatially separated, *e.g.*, in the equations for the reading on R' at the event E_0'. In fact, to talk of the reading on a clock at an event which is not coincident with that clock, is a loose usage of language. We should instead speak of the reading on R' at an event E which *is* coincident with R', and which, with respect to the co-ordinate system being considered, is simultaneous in time with the event E_0'. Stated geometrically, the existence of the clock R' is represented by a world line, any point on which corresponds to a definite reading on the clock. The event E_0', however, is represented by a point which is not on this world line and can therefore be related with a particular reading on R' only by a process of projection. Different observers, or even the same observer, can therefore obtain different results depending on the method of projection employed.

In conclusion, I should like to take this opportunity to comment on one of the points raised in Professor Dingle's previous letter[3]. I refer to his remark (in parenthesis) that some may object to my statement that M creates the gravitational field whenever his engine operates, but that this is immaterial. I admit that the concept of a rocket engine as a gravitational field generator is unconventional, yet I do not consider the matter to be immaterial, if the principle of relativity is to be fully substantiated. My argument is that since the field always appears and disappears in synchronism with the operation of the motor controls, it is surely inadmissible for M to regard this correspondence as purely fortuitous and requiring no explanation. On the other hand, if M can account for the appearance of the field only in terms of the action of his engine in accelerating the spaceship, then he has clearly forfeited his claim to be regarded as stationary.

R. HERMAN.

The Radio Research Dept.,
The Plessey Co. Ltd.,
Roke Manor,
Romsey, Hampshire.

8 *August*, 1960.

REFERENCES

1. R. Herman, *J.B.I.S.*, 1957-58, **16**, 564.
2. R. Herman, *ibid.*, 1959-60, **17**, 216.
3. H. Dingle, *ibid.*, 98.

Stationary Satellites

SIR,

In a recent paper,[1] Mr. S. W. Greenwood discusses the possibility of establishing relay satellites around other planets than the Earth, *i.e.*, satellites that are to appear as stationary with respect to the planetary surfaces.

When computing the radii of these satellite orbits, Mr. Greenwood makes the assumption that the gravitational fields of all other heavenly bodies except that of the pertinent planet itself can be neglected. I would like to draw your attention to the fact that in the extreme case of a planet with bound rotation (*e.g.*, Mercury), the gravitational influence of the Sun can quite readily be taken into account, and yields then a value for the radius which differs appreciably from that obtained under Mr. Greenwood's assumption.

If the influence of the Sun is neglected, one has for the orbital radius R of a satellite which revolves around a planet of mass m with the same period as the planet itself revolves around the Sun (mass M) in an orbit with radius A (circular orbits assumed throughout) the simple expression

$$R = \left(\frac{m}{M}\right)^{1/3} A \qquad \ldots \qquad \ldots \qquad (1)$$

which for Mercury ($m/M = 1{\cdot}634 \times 10^{-7}$, $A = 35{\cdot}97 \times 10^6$ miles) gives the value quoted by Mr. Greenwood, $R = 197{,}000$ miles.

The gravitation of the Sun can now be taken into account by noting that a satellite which is stationary with respect to the surface of a planet with bound rotation, actually is stationary in a co-ordinate system which has the Sun as its origin and which rotates uniformly so as to follow the planet's motion around the Sun. But the only possible stationary points for a particle in such a two-body system are given by the five well-known libration centres, of which only the two situated on the line Sun-planet in the neighbourhood of the planet are of interest in this context.

In a first approximation, valid when the ratio m/M is very much smaller than unity (as is indeed the case for

the system Mercury–Sun), these two libration points have the same distance to the planet, given by

$$R = \left(\frac{m}{3M}\right)^{1/3} A \quad .. \quad .. \quad (2)$$

so that the value obtained from Eq. (1) has to be corrected by a factor $(\frac{1}{3})^{\frac{1}{3}}$, or decreased by roughly 30%. The resulting distance in the case of Mercury is $R =$ 137,000 miles.

It should be noted that there are thus only two possible points for stationary satellites of Mercury, one (L_1) situated above the centre of the planet's perpetually sunlit hemisphere, the other (L_2) above the centre of its night side. As the umbra of Mercury is about 130,000 miles long, a satellite in L_2 will fortunately receive a certain amount of sunshine from the angularly eclipsed Sun, and so be able to use solar batteries.

Similar arguments can be applied to a system consisting of a planet (mass M) and a moon (mass m), the obvious case being the Earth–Moon system. Here, the ratio $m/M = 0{\cdot}0123$ is not sufficiently small for Eq. (2) to be applicable. A better approximation is then

$$R_{1,2} = \left[\left(\frac{m}{3M}\right)^{1/3} \mp \tfrac{1}{3}\left(\frac{m}{3M}\right)^{2/3}\right] A \quad .. \quad (3)$$

where the upper sign belongs to R_1, which is the distance of L_1 from m, while the lower sign belongs to R_2, the distance of L_2 from m. For the Earth–Moon system ($A = 239{,}000$ miles), Eq. (3) gives $R_1 = 36{,}200$ miles, $R_2 = 40{,}300$ miles.

The possibility of using the libration centres L_1 and L_2 of the Earth–Moon system for relay satellites has been pointed out by A. C. Clarke.[2]

Yours sincerely,

NILS MUSTELIN.

Nordita,
Blegdamsvej 17,
Copenhagen, Denmark.

19 *October*, 1960.

REFERENCES

1. S. W. Greenwood, *J.B.I.S.*, 1959–60, **17**, 360.
2. A. C. Clarke, "Interplanetary Flight", 1st edn., p. 111, **1950**: London (Temple Press).

Manned Navigation and Guidance in the Solar System

SIR,

In reference to the paper[1] by Cashmore and Gordon, the subsequent correspondence[2] brings out impressively an idea expressed in Dr. Porter's statement: "*The essential requirement in any form of orbit determination is a knowledge of velocity at a given place and time.*"

This opinion has been held in our studies of this subject. In fact, for a single attracting body the velocity in magnitude and direction and the range from attracting body determine definitely the orbit of a space vehicle of a mass infinitesimal compared to the mass of attracting planetary body. For two or more attracting bodies the distance and direction of the more distant bodies must also be determined as well as their "sphere of action." Within its sphere of action the planetary body has predominant control of the trajectory but other bodies will introduce perturbations.

The efforts to measure velocity accurately have brought out two possibilities: integrating acceleration values and differentiating a series of positional fixes. Dr. Porter clearly indicates the difficulties of these two methods.

We have studied the velocity measurements from a somewhat different viewpoint. For a single attracting body or for the predominant attraction within the sphere of action the velocity may be represented by two components: one towards the centre of the attracting body, the other at right angles to this direction.

The first can be measured by correlating successive observations of the apparent diameter of the planet. Devices for this purpose are now being studied.

The second velocity can be expressed as angular velocity relative to the attracting body multiplied by the distance to its centre. Since a device based on the apparent diameter of the attracting body gives a direct measure of this distance when the radius of the body is known, the only required measurement is the angular velocity. There is a possibility of designing a space sextant in reference to a stable inertia platform to obtain directly this angular velocity. The question of accuracy of such measurements and the technical features of such a sextant are still being investigated; it is too early to comment on their practicability.

However, if the two velocities are known, the reference to a simple velocity chart* would give all the needed orbital information. These charts are nondimensional and can be constructed with sufficient accuracy for use by the astronaut for direct and rapid determination of his course as well as for estimation of the required correctional velocity vector to bring his vessel to the most desirable trajectory.

Very truly yours,

ANDERSON-NICHOLS & COMPANY

ALEXANDER NYMAN.

150 Causeway Street,
Boston 14, Mass., U.S.A.

4 *October*, 1960.

REFERENCES

1. D. J. Cashmore and C. N. Gordon, *J.B.I.S.*, 1959–60, **17**, 46.
2. D. F. Lawden, *ibid.*, 141; M. Noton, *ibid.*, 331; J. G. Porter, *ibid.*, 382; D. J. Cashmore and C. N. Gordon, *ibid.*, 383.

* The astronautical uses of velocity charts will be presented at a coming meeting of the Washington Branch of the British Interplanetary Society (*This paper is to be published in the* Journal—EDITOR).

NEWS AND ANNOUNCEMENTS

B.I.S. NEWS

Course on Rocket Motor Technology

The Society is organizing a one-day course on Rocket Motor Technology, intended primarily for teachers, it being felt that the average teacher's lack of knowledgd concerning rocket propulsion is one of the reasons why this subject does not receive the attention it deserves in present curricula.

The course will be given at the College of Advanced Technology, Gosta Green, Birmingham, on Thursday, **30 March, 1961**.

The provisional programme is as follows:

9.30 a.m. *Registration.*

10.00 a.m. "Introduction to Propellent Chemistry," by Dr. D. Walwyn-James (Education Officer, Royal Air Force, Henlow).

11.00 a.m. "The German A4 Rocket" (film).

11.30 a.m. Demonstration of Propellent Properties, by D. S. Carton (Department of Aircraft Propulsion, College of Aeronautics, Cranfield).

12.00 *Discussion.*

12.30 p.m. *Luncheon Break.*

2.00 p.m. "Liquid Propellent Motors," by W. N. Neat (Chief Engineer, Rocket Division, The de Havilland Engine Co., Ltd.).

2.40 p.m. "Engineering Aspects of Solid Propellent Motors," by F. J. Wilkinson (Assistant Chief Engineer (Development), Bristol-Aerojet Ltd.).

3.20 p.m. "Development Testing of Rocket Engines and Their Components," by H. L. G. Sunley (Experimental Engineer, Rocket Department, Bristol-Siddeley Engines Ltd.).

4.00 p.m. *Tea.*

4.30 p.m. *Discussion.*

There will be a registration fee of 10s. 6d. (which covers admission to the course and the provision of refreshments). Members and others wishing to attend the course should notify the Secretary, British Interplanetary Society, 12 Bessborough Gardens, London, S.W.1.

Symposium on Liquid Hydrogen as a Rocket Propellent

A one-day symposium on Liquid Hydrogen as a Rocket Propellent is being organized by the Society and will be held in the Lecture Theatre of the Royal Aeronautical Society, 4 Hamilton Place, London, W.1, on Friday **28 April, 1961**.

The provisional programme is as follows:

10.00 a.m. "Liquid Hydrogen Production on an Industrial Scale," by T. J. Webster (Manager, Gas Separation Department, Scientific Division, The British Oxygen Co. Ltd.).

"Production, Storage and Handling of Liquid Hydrogen," by W. Scharle (Process Manager, Air Products (Gt. Britain) Ltd.).

"The Use of Liquid Hydrogen in Large-Scale Rockets," by A. V. Cleaver (Chief Engineer, Rocket Propulsion, Rolls Royce Ltd.).

"Design of Rocket Engines Burning Liquid Hydrogen as Fuel," by D. Hurden (Research Manager, The de Havilland Engine Co. Ltd.).

12.00 *Discussion.*

12.30 p.m. *Luncheon Break.*

2.15 p.m. "The Use of Liquid Hydrogen in the Third Stage of a Satellite Vehicle," by B. W. A. Rickerson and R. G. Cruddace (Rocket Propulsion Establishment, Westcott).

"Optimum Engine and Vehicle Coupling for Satellite Launching Stages Using Liquid Hydrogen," by M. S. S. Hunt, G. W. Brown and B. G. White (Rocket Department, Bristol-Siddeley Engines Ltd.).

"Liquid Hydrogen Behaviour in Space," by K. R. Stehling (Office of Program Planning and Evaluation, National Aeronautics and Space Administration).

"Liquid Hydrogen as a Working Fluid in Advanced Propulsion Systems," by P. A. E. Stewart (Astronautics Division, Advanced Projects Group, Hawker-Siddeley Aviation Ltd.).

"The Use of Hydrogen in Nuclear Rockets," by O. H. Wyatt (Senior Project Engineer, Hawker-Siddeley Nuclear Power Co. Ltd.).

4.15 p.m. *Tea.*

4.30 p.m. *Discussion.*

Admission is free to members of the Society. A registration fee of £1 1s. is payable by non-members. Members and others wishing to attend the symposium are asked to notify the Secretary (British Interplanetary Society, 12 Bessborough Gardens, London, S.W.1).

Symposium on Communications Satellites

A one-day symposium on Communications Satellites is being organized by the Society and will be held in the Council Room, Federation of British Industries, 21 Tothill Street, London, S.W.1, on Friday, **12 May, 1961**.

The provisional programme is as follows:

10.00 a.m. "The Engineering and Economics of Satellite Communication Systems," by G. K. C. Pardoe (Chief Weapons Research Engineer, The de Havilland Aircraft Co. Ltd.).

"Operation and Economics of Preferred Communications Satellite System," by Dr. E. K. Sandeman (Head of Special Projects Group, GW Division, English Electric Aviation Ltd.).

"Some Practical Problems of Satellite Communications," by Dr. J. R. Pierce (Director of Research Communications Principles, Bell Telephone Laboratories Inc.).

"Communications Satellite Systems Suitable for Commonwealth Telecommunications," by Dr. W. F. Hilton (Head, Advanced Projects Division, Hawker-Siddeley Aviation Ltd.).

11.40 a.m. *Discussion.*

12.30 p.m. *Luncheon Break.*

2.15 p.m. "The Synchronous Communications Satellite," by R. P. Havilland (Missile and Space Vehicle Department, General Electric Co., U.S.A.).

"Active Communications Satellites," by Dr. G. E. Mueller (Associate Director, Research and Development Division, Space Technology Laboratories, Inc.).

"The Courier Satellite," by G. F. Senn and P. W. Siglin (Project Director and Project Manager, U.S. Army Signal Research and Development Laboratory).

"Low-Cost Communications Satellites," by A. M. Peduzzi (Aerospace Consultant).

4.30 p.m. *Discussion.*

Abstracts of most of the papers were printed on p. 462 of the December, 1960, issue of the *Journal*.

Admission is free to members of the Society. A registration fee of £1 1s. is payable by non-members. Members and others wishing to attend the symposium are asked to notify the Secretary (British Interplanetary Society, 12 Bessborough Gardens, London, S.W.1).

Extension of Library Facilities

As from 1 January, 1961, the Society's postal lending library has been made available to Corporate Members, Associate Fellow and Senior Members resident in the United Kingdom, as well as to Fellows of the Society resident here (previously the only grade entitled to this privilege). A list of books is obtainable on request. Books may normally be borrowed for a period not exceeding one month, but in special cases an extension can be granted, provided that the request is received in good time and does not inconvenience other borrowers.

It is also planned to institute a small Reference Library and to extend the service to members by obtaining relevant books or locating special information, although this is dependent upon obtaining the services of an Honorary Librarian. Members of the Society resident in the London area who would like to be considered for this position are invited to apply to the Secretary.

London Lectures: Change of Programme

Members are asked to note that the venue selected for the London meetings on 4 March, 8 April and 6 May, 1961, will be the new Lecture Theatre, Royal Aeronautical Society, 4, Hamilton Place, London, W.1, and not Caxton Hall as previously stated. The dates, times and speakers remain unchanged.

The new Theatre is fully equipped with modern facilities, including high-powered projection equipment, public address and translation systems. It seats 310, but overflow facilities provided with closed-circuit television enable more people to be accommodated if necessary. It should prove a great advance on our previous venue, which is why Council has thought it worth while to alter previously announced arrangements. It is hoped that there will be an excellent attendance at these meetings.

Hamilton Place runs northwards from Piccadilly, not far from Hyde Park Corner Underground Station.

Washington Branch Secretary

Mrs. Helen V. Whittington (1007 G Street, Alexandria, Virginia, U.S.A.) has replaced Mr. J. O. Leonard as Secretary of the Metropolitan Washington Branch of the Society.

Abstracting Panel

We are endeavouring to extend and improve the *Astronautical Abstracts* section of the *Journal*, but to do this we need to enlarge the abstracting panel. Members who would be willing to undertake the abstracting of one or more periodicals are asked to inform the Editor (1 Herbert Road, Hornchurch, Essex) of the subjects in which they specialize and which languages they can read. Abstractors for astronomy and space physics are particularly needed, but all offers would be welcomed.

JOINT ACTIVITIES

European Symposium on Space Technology

Members are reminded that a European Symposium on Space Technology is being organized by the Society, with the cooperation of other principal European astronautical societies. This has aroused considerable interest and many offers of papers have been received—in fact, more than could be presented in the time available. It has therefore proved necessary to limit the number of British contributions.

The provisional programme for the Symposium will appear in the next issue of the *Journal*, but members and others considering attending the Symposium are advised to apply as soon as possible, as attendance must be limited to 300.

The official languages of the Symposium are English, French and German, and simultaneous translation equipment is being installed, so that both lectures and discussion will be available throughout in each of these languages. It is intended to provide preprints of the papers; where these are not in English, translations into English will also be preprinted.

Arrangements have been made for professional conference interpreters to undertake the simultaneous translation service, but interpreters are also required to help with registration and general enquiries, and to translate papers for preprinting. Offers of assistance from linguists and from members prepared to act as stewards will be welcomed by the Secretary.

The Symposium is to take place in the Council Room of the Federation of British Industries, 21, Tothill Street, London, S.W.1, from Monday, **26 June**, to Wednesday, **28 June, 1961** inclusive, Monday and Tuesday will be devoted to technical papers, Wednesday to a general discussion on European Collaboration. The registration fee for attendance at the symposium is £5 5s.; this will also cover the cost of attendance at a reception and the provision of preprints. Applications should be sent to the Secretary, British Interplanetary Society, 12, Bessborough Gardens, London, S.W.1.

Twelfth International Astronautical Congress

The venue of the Twelfth International Astronautical Congress has been changed since the preliminary announcement was printed in the December, 1960, issue of the *Journal* (p. 464). The American Rocket Society has now arranged for the Congress to be held in Washington, D.C., on **2–6 October, 1961.**

No details of the programme can be expected for some months, but if it follows the pattern for previous Congresses, in addition to lecture sessions there will be a Government reception, excursions to historic places, visits to research establishments, a ladies' programme, etc. This Congress should be a memorable occasion.

As mentioned in the previous announcement, the Society hopes to charter an aircraft to attend the Congress; it is possible that the charter flights can be arranged in such a way that members can also attend part of the A.R.S. Annual Meeting to be held in New York, 9–14 October. Members who think that there is a possibility that they might wish to participate in the charter flight are asked to notify the Secretary immediately. There is no need to make a definite commitment just yet.

ASTRONAUTICAL ABSTRACTS

Edited by J. HUMPHRIES

1961–62 PART 1

Abstracting panel:

C. FLEISHER
J. FOLEY.
J. S. GRIFFITH.
HAWKER SIDDELEY AVIATION LTD.; ADVANCED PROJECTS GROUP.
C. E. S. HORSFORD.
J. HUMPHRIES.
A. E. SLATER.
G. V. E. THOMPSON.
E. WHITE.

For full titles of journals see list of abbreviations to be published in the 1959–60 index.

The following abstracts refer to books noted in this issue: 14, 54, 63–67, 76, 112, 167, 188, 231–2, 288, 291–2.

1—ASTRONOMY

.5 *Planets*

(1) **The colour of Venus and the nature of its clouds.** F. Link and L. Neužil. *Bull. Astronom. Insts. Czech.*, **8**, 23–7 (1 *March*, 1957). (*In French.*) (25 *refs.*)

(2) **Conditions on Mars.** C. A. Cross. *Spaceflight*, **2** (1), 25–9 (*Jan.*, 1959). Basic astron. data, areography, surface conditions, Martian meteorology, etc.

(3) **Radar echoes from Venus.** R. Price, P. E. Green, T. J. Goblick, R. H. Kingston, L. G. Kraft, G. H. Pettengill, R. Silver and W. B. Smith. *Science*, **129**, 751–3 (20 *March*, 1959). (7 *refs.*)

(4) **The rotational period and tilt of the planet Venus.** F. C. Wykes. *Spaceflight*, **2** (2), 63–4 (*April*, 1959). Reviews published estimates. (13 *refs.*)

(5) **Radiometric observations of Mars and Venus.** W. M. Sinton and J. Strong. *Astrophys. J.*, **131** (2), 459–90 (*March*, 1960). Central disk temperature of Mars found to be 15° C. Temperature of dark areas few degrees warmer than adjacent bright areas. From spectrum, surface silicates not present in large proportions. Central disk temperature of Venus found to be −39° C. Dark side nearly as hot as bright side. (39 *refs.*)

.7 *Moon*

(6) **The Alphonsus outbreak.** P. Moore. *Spaceflight*, **2** (1), 11, 21 (*Jan.*, 1959). Discusses volcanic outbreak reported in crater Alphonsus on night of 3–4 Nov., 1958. (6 *refs.*)

(7) **Dust on the Moon.** F. A. Lugo. *Strolling Astronomer*, **13**, 23–7 (*Jan.–April*, 1959).

(8) **What is topography of Moon's other side?** I. M. Levitt. *Missiles and Rockets*, **5** (7), 14–15 (16 *Feb.*, 1959).

(9) **The extent of the lunar atmosphere.** G. Turner. *Spaceflight*, **2** (2), 57–8 (*April*, 1959). Discussion in terms of kinetic theory of gases.

2—PHYSICS

.1 *General*

(10) **A solution of the clock paradox.** G. Contopoulos. *Ann. Faculty Sci. Univ. Thessalonika*, **8**, 23–41 (1958). (67 *refs.*)

(11) **Scale of separation phenomena in liquids under conditions of nearly free fall.** E. T. Benedikt. *ARS J.*, **29**, 150–1 (*Feb.*, 1959).

(12) **Further proof of the general theory of relativity using Earth satellites.** F. Winterberg. *Weltraumfahrt*, **10**, 33–8 (*March*, 1959). (*In German.*) (8 *refs.*)

(13) **The clock paradox.** C. C. MacDuffee. *Science*, **129**, 1359 (15 *May*, 1959). (1 *ref.*)

.2 *Gravitation*

(14) **Gravity and interplanetary travel.** M. Goodrich. $2.50, 72 pp. *Vantage Press, N.Y.*

(15) **Gravity and the prospect for astronautics.** A. R. Weyl. *Aeronautics*, **39** (6), 16–22 (*Feb.*, 1959). (37 *refs.*)

.5 *Heat and Thermodynamics*

(16) **Thermodynamics of Al_2O_3.** M. Farber. *Jet Propulsion*, **28**, 760–2 (*Nov.*, 1958). (7 *refs.*)

(17) **Algebraic methods of calculation of the equilibrium composition of the products of high energy reaction.** E. Le Grivès and S. Barrère. *Rech. Aéronaut*, **68**, 31–7 (*Jan.*, 1959). (5 *refs.*) (*In French.*)

(18) **Energy transfer at a chemically reacting or slip interface.** S. M. Scala and G. W. Sutton. *ARS J.*, **29**, 141–3 (*Feb.*, 1959). (5 *refs.*)

(19) **Re-entry heat transfer.** L. Lees. *Astronautics*, **4** (3), 22–3, 60, 62, 65 (*March*, 1959). Brief review of heat transfer mechanisms in various possible coolant systems.

(20) **Some contributions to the analysis of heat conduction and thermal stresses in aircraft and missile structures.** L. Broglio. *Aerotecnica*, **34** (2), 53–65 (*April*, 1959). (*In Italian.*) Analysis of temperature distribution for bodies subjected to kinetic heating and heat loss by radiation, also the case of boundary conditions determined by time and surface temperature distribution. A general case and particular applications are developed. (12 *refs.*)

.8 *Other Upper Atmosphere Phenomena*

(21) **Advancing the "vertical frontier."** R. Hawthorne and V. DeBiasi. *Space-Aeronautics*, **30** (6), 22–3, 193 (*Dec.*, 1958). Report on papers presented at the Second International Symposium on the Physics and Medicine of the Atmosphere and Space, San Antonio, Texas, November, 1958. Includes a list of titles of papers.

(22) **A radioactive ionization gage pressure measurement system.** N. W. Spencer and R. L. Boggess. *ARS J.*, **29** 68–71 (*Jan.*, 1959).

(23) **Frontal cloud system pictures obtained by rocket.** *Science*, **129**, 198–200 (23 *Jan.*, 1959).

(24) **IGY solar flare program and ionizing radiation in the night sky.** H. Friedman. *ARS J.*, **29**, 103–7 (*Feb.*, 1959). (10 *refs.*)

(25) **On the use of ionization gage devices at very high altitude.** N. W. Spencer, R. L. Boggess, H. W. Lagow and R. Horowitz. *ARS J.*, **29**, 290–4 (*April*, 1959). (21 *refs.*)

(26) **Scientists at Space Agency Seminar compare views on composition and origin of Van Allen radiation layer.** R. Jastrow. *Science*, **129**, 1012–3 (17 *April*, 1959).

3—CHEMISTRY AND MATERIALS

.2 *Chemistry*

(27) **Recent advances in fluorine chemistry and technology.** J. F. Gall. *ARS J.*, **29**, 95–103 (*Feb.*, 1959). (136 *refs.*)

.4 *Refractories*

(28) **New aspects in ceramic coatings.** P. A. Huppert. *ARS J.*, **29**, 19–21 (*Jan.*, 1959). (10 *refs.*)

(29) **Missile needs pose challenges for ceramics.** R. T. Inglis and D. L. Krout. *Missiles and Rockets*, **5** (10), 34–7 (9 *March*, 1959).

.6 *Miscellaneous*

(30) **Safety aspects in the handling and storage of liquid hydrogen.** L. H. Cassutt, F. E. Maddocks and W. A. Sawyer. *Arthur D. Little, Inc.*, 19 pp. (7 *refs.*)

4—BIOLOGY AND MEDICINE

.1 *General*

(31) **Soviet biological experiments.** I. Hersey. *Astronautics*, **4** (2), 31, 80–1 (*Feb.*, 1959). Mainly an account of information on experiments in *Sputnik II* and high-altitude rockets, given by A. G. Kuznetsov at the 3rd European Congress of Aviation Medicine, Louvain, Sept., 1958.

(32) **Meteorites and the origin of life.** M. H. Briggs. *Spaceflight*, **2** (2), 39–43 (*April*, 1959). Considers possibility of life on the Earth having arisen as a result of the arrival of spores carried by meteorites. (12 *refs.*)

.4 *Anatomy and Physiology*

(33) **USAF school simulates living in space.** *Aviation Wk.*, **68** (4), 49, 51, 53, 55, 57–9, 61 (27 *Jan.*, 1958). Activities at the Randolph A.F.B. and other U.S.A.F. centres on subjects connected with life in space. Cabin conditions, physical and psychological, weightlessness, effects of fatigue, food supplies and motion sickness are being investigated.

(34) **Human factors geared to spaceflight.** R. Hawkes. *Aviation Wk.*, **68** (9), 167, 169, 171 (3 *March*, 1958). Current work on man as a part of a spaceflight control system, and his advantages and limitations for this work.

(35) **Survival in space.** J. Ryan. *Air B.P.* (10), 30–4 (1959) Popular.

(36) **Reports on space medicine—1958.** *Air Univ., School of Aviation Medicine, USAF, Randolph A.F.B.* (*Feb.*, 1959). Consists of reprints of the following papers: **Human performance in the space travel environment.** G. T. Hauty. *Air Univ. Quart. Rev.* (1958). **Supersonic and hypersonic human flight.** J. E. Ward, S. J. Gerathewohl and G. R. Steinkamp. *Inst. Aeronaut. Sci. Reprint No.* 797 (27–30 *Jan.*, 1958). **Human engineering of the sealed space cabin.** J. E. Ward and G. R. Steinkamp. *Texas State J. Med.*, **54**, 356–7 (*June*, 1958). **Fatigue, confinement, and proficiency decrement.** G. T. Hauty and R. B. Payne. *Vistas in Astronautics*, **1**, 304–9 (1958). **The feasibility of recycling human urine for utilization in a closed ecological system.** W. R. Hawkins. *J. Aviation Medicine*, **29**, 525–35 (*July*, 1958). [See abs. no. 737, *J.B.I.S.*, **17**, 152 (*Sept.–Oct.*, 1959).] **Space cabin requirements as seen by subjects in the space cabin simulator.** W. R. Hawkins and G. T. Hauty. *A.R.S. Preprint* (*Nov.*, 1958). **Weightlessness. The problem and the Air Force research program.** S. J. Gerathewohl. *Air Univ. Quart. Rev.* (1958).

(37) **Capsule for man in space.** *Astronautics*, **4** (2), 30, 74, 77 (*Feb.*, 1959). General Electric Co., U.S.A., designs.

(38) **They float through the air.** I. H[ersey]. *Astronautics*, **4** (2), 42–3 (*Feb.*, 1959). U.S.A.F. Aero Medical Lab. weightlessness experiments in Convair C-131B transport.

(39) **Water recovery in a space cabin.** R. A. Bambenek and J. D. Zeff. *Astronautics*, **4** (2), 34–5, 112–3 (*Feb.*, 1959). American Machine and Foundry Co.'s distillation system for urine and wash-water.

(40) **Weightlessness and space flight.** H. J. von Beckh. *Astronautics*, **4** (2), 26–7, 84, 86 (*Feb.*, 1959). Report of aeromedical aircraft experiments.

(41) **Preparing man for space.** C. C. Clark and J. D. Hardy. *Astronautics*, **4** (2), 18–21, 88, 90 (*Feb.*, 1959). Acceleration studies at U.S. Naval Air Development Center, Johnsville, Pa.

(42) **Biodynamics of space flight.** E. P. Hiatt. *Astronautics*, **4** (2), 24–5, 70, 72, 74 (*Feb.*, 1959). Acceleration studies at Wright-Patterson A.F.B., Ohio.

(43) **Hazards of sealed cabins.** E. B. Konecci. *Astronautics*, **4** (2), 40–1, 48–9, 51 (*Feb.*, 1959). Acceleration, noise, vibration, weightlessness, CO_2 and other waste gases, decompression, radiation, temperature extremes, psychological problems, reliability factors.

(44) **A closed-cycle breathing/ventilation system.** W. B. Moen and P. Webb. *Astronautics*, **4** (2), 36–7, 102 (*Feb.*, 1959). System developed by Air Reduction Co. and Wright-Patterson A.F.B.

(45) **Selecting a space cabin atmosphere.** K. E. Schaefer. *Astronautics*, **4** (2), 28–9, 104, 106 (*Feb.*, 1959). Choice of CO_2 content and cabin pressure; control of impurities, etc.

(46) **Acceleration: how great a problem?** J. P. Stapp. *Astronautics*, **4** (2), 38–9, 98–100 (*Feb.*, 1959).

(47) **Investigation of the effect of weightlessness on human bodies.** H. J. von Beckh. *Weltraumfahrt*, **10**, 21–8 (*March*, 1959). (*In German.*) (28 *refs.*)

(48) **Astronauts will require less sleep.** D. Zylstra. *Missiles and Rockets*, **6** (9), 33–4 (29 *Feb.*, 1960). Reports requirements during extended immersion in water for weightlessness.

.7 *Psychology*

(49) **Work helps man endure space isolation.** *Aviation Wk.*, **68** (11), 37, 39, 43, 45, 47 (17 *Mar.*, 1958). Conditions in a simulated space capsule and experiences of subjects who underwent isolation tests of 2-days' duration.

(50) **Isolation.** G. E. Ruff. *Astronautics*, **4** (2), 22–3, 110–11 (*Feb.*, 1959). Isolation as a cause of psychological stress in spaceflight.

(51) **Psychophysiological aspects of Manhigh.** D. G. Simons. *Astronautics*, **4** (2), 32–3, 62–3 (*Feb.*, 1959). Report on Manhigh flights I–III; evaluation of candidates.

(52) **Psycho-social problems of manned space flights.** G. A. Peters. *Astronautics*, **5** (3), 30–1, 89–92 (*March*, 1960). Analysis of work done to date on human factors indicates the need for a full-scale study of the psychological, social and sexual behaviour of spaceship crew members.

5—AVIATION AND AERODYNAMICS

.2 *Aerodynamics*

[*See also* abstracts nos. 19, 94]

(53) **Stationary wall temperatures of bodies undergoing aerodynamic heating at Mach numbers of 1 to 10 and at altitudes up to 30 kilometers.** H. G. L. Krause and M. E. Kubler. *Forschungsinstitut für Physik der Strahlantriebe. Rept.* 7, 138 pp. (*Oct.*, 1957).

(54) **Missile aerodynamics.** J. N. Nielson. 450 pp. *McGraw-Hill, London and New York* (1959). Some formulae commonly used in missile aerodynamics. Slender-body theory at supersonic and subsonic speeds. Aerodynamics of bodies; vortices. Wing-body interference. Downwash, sidewash, and the wake. Wing-tail interference. Aerodynamic controls. Drag. Stability derivatives.

(55) **Effect of unequal wall roughness on flow between flat plates.** H. N. McManus. *ARS J.*, **29**, 144–5 (*Feb.*, 1959). (2 *refs.*)

(56) **Contribution to magnetofluiddynamics. Pt. 1.** L. Napolitano. *Missili*, **1**, 15–34 (*Feb.*, 1959). (*In Italian.*) (9 *refs.*)

(57) **Hypersonic aerodynamics.** W. D. Hayes. *Astronautics*, **4. Part I** (3), 24–5, 72, 74 (*March*, 1959). **Part II** (4, Pt. 1), 34–5, 83–4, 86 (*April*, 1959).

(58) **Magnetohydrodynamics and aerodynamic heating.** R. X. Meyer. *ARS J.*, **29**, 187–92 (*March*, 1959). (15 *refs.*)

(59) **Aerodynamic moment on bodies moving at high speed in the upper atmosphere.** W. A. Gustafson. *ARS J.*, **29**, 301–3 (*April*, 1959). (2 *refs.*)

.3 *Rocket-Propelled Aircraft*

(60) **First manned U.S. spacecraft: X-15 design details.** I. Stambler. *Aviation Age*, **30** (1), 22–3, 144–9 (*July*, 1958). Details of structural arrangement, materials and methods of construction of this aircraft.

.4 *Test Facilities*

(61) **A method for simulating the atmospheric entry of long-range ballistic missiles.** A. J. Eggers. *N.A.C.A. Rept.* 1378 (1958). Proposes the use of hypervelocity gun to project models upstream through the flow from a supersonic nozzle.

(62) **Arc-heated plasma for laboratory hypersonics.** T. R. Hogness. *Astronautics*, **4** (3), 40–2, 47 (*March*, 1959).

6—ASTRONAUTICS

.1 *General*

[*See also* abstracts nos. 14, 15, 167–8, 231, 258]

(63) **Take-off into space.** W. von Braun. 320 pp. *S. Fischer Verlag, Frankfurt.* (1958). (*In German.*)

(64) **Countdown for tomorrow.** M. Caidin. 277 pp. $4.95. *Dutton, N.Y.* (1958).

(65) **On the threshold to space.** H. von Diringshofen, W. G. Fesenkow, F. Hecht, R. Jungk and E. Sänger. 138 Aust. Sch., 228 pp., *Wilhelm Frick-Verlag, Vienna* (1958). (*In German.*)

(66) **Spaceflight.** O. W. Gail and W. Petri. 150 pp. *Hanns Reich Verlag, Munich* (1958). (*In German.*)

(67) **Satellites, rockets and outer space.** W. Ley. 3s. 6d. 128 pp., *Muller, London* (1958). *Signet Key Books, N.Y.* (1958).

(68) **"Sublimation" may lick re-entry problem.** K. R. Stehling. *Aviation Age*, **28** (8), 27–9 (*Feb.*, 1958).

(69) **Thermodynamics.** R. A. Budenholzer and A. Ritter. *Aviation Age*, **28** (9), 44, 46–9 (*March*, 1958). A review of the thermodynamic and heat transfer problems of spaceflight.

(70) **Ground support.** B. Cain. *Aviation Age*, **28** (9), 98–101 (*March*, 1958). A short résumé of launch problems and vehicle recovery.

(71) **Blueprint for space research.** H. E. Newell and K. R. Stehling. *Aviation Age*, **28** (9), 28–9, 106–8, 111–12 (*March*, 1958).

(72) **Development of manned space flight.** W. A. Orr and J. N. Tucker. *Aviation Age*, **28** (9), 14–20 (*March*, 1958).

(73) **Accessories.** R. L. Wehrli. *Aviation Age*, **28** (9), 90–2, 94–6 (*March*, 1958). Power supplies, food and atmosphere regeneration, and thermal control of the life-capsule are discussed.

(74) **Thin pressurised shells look best for space structures.** J. S. Lewin. *Aviation Age*, **29** (4), 178–9, 181–5 (*April*, 1958).

(75) **Exit and re-entry problems.** G. V. Bull, K. R. Enkenhus and G. H. Tidy. *Aero-Space Engng.*, **17** (6), 56–62 (*June*, 1958).

(76) **Soviet sputniks and cosmic rockets.** C. G. Aleksandrov and R. E. Federov. 3r. 50 k., 232 pp. *Akademii Nauk. U.S.S.R* (1959). (*In Russian.*)

(77) **Re-entry.** F. C. Durant. *Air B.P.* (11), 23–7 (1959). Popular.

(78) **Rockets leave the Earth.** M. Kroshkin. 1r. 5k., 88 pp. *Moscow* (1959). (*In Russian.*) Popular.

(79) **Space digest.** *Air Force Mag.*, **42** (1). 59–83 (*Jan.*, 1959). Popular survey.

(80) **The I.A.F. at Amsterdam.** A. E. Slater. *Spaceflight*, **2**, 18–21 (*Jan.*, 1959).

(81) **Committee on Space Research. Draft report on first meeting, London, Nov. 14–15, 1958.** *Internat. Sci. Radio Union. Inf. Bull.* (113), 94–106 (*Jan.–Feb.*, 1959).

(82) **Decimal classification for astronautics.** *Raktech. Raumforsch.*, **3**, 1–8 (*Jan.–March*, 1959). (*In German.*)

(83) **The radiation band can be avoided.** *Alata*, **15** (164), 56–7 (*Feb.*, 1959). (*In Italian.*)

(84) **The IXth International Astronautical Congress.** A. Eula. *Missili*, **1**, 83–7 (*Feb.*, 1959). (*In Italian.*)

(85) **The technology of manned return from outer space.** H. W. Paige. *J. Franklin Inst.*, **267**, 103–18 (*Feb.*, 1959).

(86) **The birth and growth of astronautics.** D. C. Wallis. *Proc. Canad. Astronaut. Soc.*, **1** (1), 7–15 (*Feb.*, 1959).

(87) **Re-entry: problems and progress.** C. du P. Donaldson. *Astronautics*, **4** (3), 38–9, 108 (*March*, 1959).

(88) **Heat protection for re-entry vehicles.** N. F. Dow. *Astronautics*, **4** (3), 28–9, 82, 84, 86 (*March*, 1959).

(89) **Design and fabrication of a re-entry vehicle.** L. L. Farnham. *Astronautics*, **4** (3), 26–7, 57–8 (*March*, 1959).

(90) **Planning a re-entry and recovery test program.** W. R. Lucas and M. E. Huston. *Astronautics*, **4** (3), 30–1, 88 (*March*, 1959).

(91) **The nature of re-entry.** G. E. Solomon. *Astronautics*, **4** (3), 20–1, 98, 100 (*March*, 1959).

(92) **The United Nations debate on space.** J. A. Joyce. *Discovery*, **20**, 106–9 (*March*, 1959).

(93) **Dynamic stability of re-entry vehicles.** M. Tobak. *Astronautics*, **4** (3), 32–3, 66 (*March*, 1959).

(94) **Flight of a space-ship through the atmosphere.** Z. Brodzki. *Technika Lotnicza*, **14**, 35–41 (*March–April*, 1959). (*In Polish.*) (11 *refs.*)

(95) **Careers in astronautics.** *Astronautics*, **4** (4 Pt. 2), 21–3, 25–6, 28–31 (*April*, 1959). Write-ups from various firms in rocket and missile industry.

(96) **Thoughts on the structure of space vehicles.** G. Catteneo. *Alata*, **15** (166), 53–6 (*April*, 1959). (2 *refs.*)

(97) **Towards a Commonwealth Space Agency.** K. W. Gatland. *Spaceflight*, **2**, 35–7, 64 (*April*, 1959).

(98) **A philosophy of astronautics?** S. W. Greenwood. *Spaceflight*, **2**, 38–9 (*April*, 1959). (5 *refs.*)

(99) **Keeping up to date on Soviet astronautics.** F. J. Krieger. *Astronautics*, **4** (4 Pt. 1), 30–2, 76 (*April*, 1959).

(100) **Space and the universe—the beginnings**. F. B. Pollard. *Spaceflight*, **2**, 45–7 (*April*, 1959).

(101) **Educational opportunities in astronautics**. P. Sandorff. *Astronautics*, **4** (4 Pt. 2), 2–6 (*April*, 1959).

(102) **What will be needed in GSE when man enters the missile**. H. Gettings. *Missiles and Rockets*, **5** (16), 20–2 (20 *April*, 1959).

(103) **Needed: new velocity measurement unit for space**. W. C. Mannix. *Missiles and Rockets*, **5** (17), 21–2 (27 *April*, 1959).

(104) **Tenth International Astronautical Congress**. G. V. E. Thompson. *Aircraft Engng.*, **31**, 373–6 (*Dec.*, 1959). Summaries of 62 of the more important papers given at the congress held in London, 1959.

(105) **Advantages of high-thrust space vehicles**. M. W. Hunter and J. M. Tschirgi. *Astronautics*, **5** (2), 28–9, 99–102 (*Feb.*, 1960). High-thrust nuclear propulsion vehicles compare well in performance with their low-thrust counterparts and offer important advantages from the standpoint of development for reliability. (4 *refs.*)

(106) **How useful are low-thrust space vehicles?** E. Stuhlinger. *Astronautics*, **5** (2), 23–6, 95–7 (*Feb.*, 1960). Interplanetary orbits using a system of ion propulsion.

.2 *Artificial Satellites*

[*See also* abstracts nos. 12, 76, 140–3, 146, 152, 158, 163]

(107) **Vanguard sequence diagram**. *U.S. Naval Lab. PB*131922, 75 c., 15 pp.

(108) **Photos show *Sputnik II* instrumentation**. *Aviation Wk.*, **68** (1), 38–9 (6 *Jan.*, 1958).

(109) **Blunt stainless-steel nose cone indicates satellite heating problem**. G. L. Christian. *Aviation Wk.*, **68** (10), 36–7 (10 *March*, 1958). Mainly concerned with method of production.

(110) **Explorer has steel shell**. I. Stambler. *Aviation Age*, **29** (5), 172–3 (*May*, 1958).

(111) **Satellite technology and space navigation**. H. Ruppe. *Army Ballistic Missile Agency DSP–TN–9–58*, 130 pp. (9 *Sept.*, 1958. (11 *refs.*)

(112) **Artificial satellites**. A. Sternfeld. 311 pp. *B. G. Teubner, Leipzig* (1959). (*In German.*) Translated from the Russian.

(113) **Atlas will launch a man into space**. *Alata*, **15** (163), 52–6 (*Jan.*, 1959). (*In Italian.*) Project Mercury.

(114) **Lockheed space stations interesting U.S. Agencies**. N. L. Baker. *Missiles and Rockets*, **5** (3), 19–20, 32 (19 *Jan.*, 1959).

(115) **National Aeronautics and Space Administration has outline for manned satellite program**. *Science*, **129**, 256–8 (30 *Jan.*, 1959).

(116) **Terminal phase of satellite entry into the Earth's atmosphere**. E. D. Katzen. *ARS J.*, **29**, 147–8 (*Feb.*, 1959). (4 *refs.*)

(117) **The importance of Earth satellites**. C. Camposampiero. *Alata*, **15** (165), 59–60 (*March*, 1959). (*In Italian.*)

(118) **Satellites: tools of space research**. T. R. F. Nonweiler. *Aeronautics*, **40** (1), 22–6 (*March*, 1959).

(119) **The manned satellite**. J. P. Rabate. *Science et Vie* (498), 46–53 (*March*, 1959). (*In French.*) Popular.

(120) **Precise tracking of the trajectory of a satellite**. W. Thompson. *Missili*, **1** (2), 37–53 (*April*, 1959). (*In Italian.*)

(121) **Review of contemporary satellite information**. G. Yanow. *Griffith Observer*, **23**, 46–55 (*April*, 1959).

(122) **What we have learned from Vanguard**. M. Rosen. *Astronautics*, **4** (4 Pt. 1), 28–9, 110–1 (*April*, 1959).

(123) **Vanguard testing**. W. E. Howard. *Missiles and Rockets*, **5** (14), 20–1 (6 *April*, 1959).

(124) **Satellites and rockets**. V. E. Suomi and D. S. Johnson. *Amer. Meteor. Soc. Symp. on Satellite Meteorology Paper* (4 *May*, 1959).

.3 *Lunar and Planetary Probes*

(125) **Ford subsidiary speeds space study**. I. Stone. *Aviation Wk.*, **68** (1), 51, 53, 55–6 (6 *Jan.*, 1958). Work on lunar probe projects by Aeronutronic Systems Ltd.

(126) **U.S.A.F. plans Moon strike within months**. *Aviation Wk.*, **68** (3), 26–7 (20 *Jan.*, 1958). Plans for firing a lunar probe, high-altitude nuclear tests, and other space projects.

(127) **Balloon-launched vehicle may be first on the Moon**. K. R. Stehling. *Aviation Age*, **28** (9), 32–5 (*March*, 1958).

(128) **Moon looks promising as manned space station**. K. R. Stehling. *Aviation Age*, **29** (5), 22–3, 180 (*May*, 1958).

(129) **Designing a Mars-probe computer**. C. F. O'Donnell. *Space-Aeronautics*, **30** (6), 182–7, 190–2 (*Dec.*, 1958). Need for a computer for a chemical and ion-propelled Mars probe. A digital system is proposed, block diagrams of components are given.

(130) **Some suggested observations of Moon rockets**. W. H. Haas. *Spaceflight*, **2**, 12–13, 21 (*Jan.*, 1959). (9 *refs.*)

(131) **Pioneer: an achievement**. F. Pollard. *Spaceflight*, **2**, 7–10 (*Jan.*, 1959).

(132) **Rocket on the Moon**. T. W. Rackham. *Spaceflight*, **2**, 3–6 (*Jan.*, 1959).

(133) **The Moon pioneers**. J. Strong. *Aeronautics*, **39** (5), 35–7 (*Jan.*, 1959). Comment on Verne's spaceship.

(134) **Shooting the Moon**. *Griffith Observer*, **23**, 14–22 (*Feb.*, 1959).

(135) **Propulsion for Moon-landing maneuvers**. S. Dobrin. *Missile Des. Dev.*, **5** (3), 24–5 (*March*, 1959).

.5 *Interstellar and Intergalactic Travel*

(136) **Interstellar travel and measurement of time**. C. L. Musatti. *Riv. Med. Aeronaut. Spaz.*, **22**, 3–16 (*Jan.–March*, 1959). (*In Italian.*)

.6 *Orbits*

[*See also* abstracts nos. 111, 120, 129]

(137) **Guidance and control**. P. A. Castruccio. *Aviation Age*, **28** (9), 64–8 (*March*, 1958). Discusses methods of navigation in space, and problems of control and communications.

(138) **Orbits**. S. Herrick and R. M. Baker. *Aviation Age*, **28** (9), 70–1, 73–7 (*March*, 1958). Discusses optimum interplanetary orbits, and perturbations affecting them.

(139) **New engineering regime: orbit mechanics**. K. E. Gray. *Aviation Age*, **29** (6), 174–8, 180–1 (*June*, 1958).

(140) **A simple method for determining the orbit of a close Earth satellite**. B. Onderlička. *Bull. Astronom. Insts. Czech.*, **9**, 191–4 (1 *Sept.*, 1958). (*In Russian.*) (1 *ref.*)

(141) **Optical observations of artificial satellites, made at the Astronomical Observatory of Bucarest. Station No. 131**. *Stud. Cerc. Astronom. Seism.*, **4**, 423–33 (1959). (*In Roumanian*).

(142) **Observations of artificial satellites at Meudon**. P. Muller. *Bull. Astronom.*, **22**, 155–70 (1959). (*In French.*) Description of apparatus and methods used. Example of set of observations during one transit. Periods of revolution for 1958 δ_1 from Meudon observations.

(143) **Determination of the geocentric position of an artificial satellite from the observations of two stations**. C. Popovici. *Stud. Cerc. Astronom. Seism.*, **4**, 299–304 (1959). (*In Roumanian.*) (2 *refs.*)

(144) **Spatial attitude control of a spinning rocket cluster**. W. Haeussermann. *ARS J.*, **29**(1), 56–8 (*Jan.*, 1959). (3 *refs.*)

(145) **The cluster spin control system for Jupiter C missiles**. N. Jasper and D. Teuber. *ARS J.*, **29**, 58–61 (*Jan.*, 1959). (3 *refs.*)

(146) **Characteristic velocity for changing the inclination of a circular orbit to the equator**. L. Rider. *ARS J.*, **29**, 48–9 (*Jan.*, 1959).

(147) **A proposed Kepler diagram**. R. L. Sohn. *ARS J.*, **29**, 51–4 (*Jan.*, 1959). (2 *refs.*)

(148) **Re-entry navigation: 'breakthrough' is not required**. R. M. Nolan. *Missiles and Rockets*, **5** (4), 29–30, 32 (26 *Jan.*, 1959).

(149) **The law of time in Keplerian motion**. E. Cremona. *Missili*, **1**, 35–9 (*Feb.*, 1959). (*In Italian.*)

(150) **A space ship flight simulator**. C. A. Cross. *Aeronautics*, **39** (6), 28–30 (*Feb.*, 1959). (5 *refs.*)

(151) **Two simple equations for orbital mechanics**. W. H. T. Loh. *ARS J.*, **29**, 146–7 (*Feb.*, 1959).

(152) **Determination of elements of an elliptic orbit from the orbital velocity vector**. H. Munick. *ARS J.*, **29**, 150 (*Feb.*, 1959). (2 *refs.*)

(153) **Rapid method for computing high altitude gravity turns**. R. L. Sohn. *ARS J.*, **29**, 139–41 (*Feb.*, 1959).

(154) **Interplanetary guidance for man in space**. L. S. Brown. *Missiles and Rockets*, **5** (6), 67–8, 70, 72, 75–6 (9 *Feb.*, 1959).

(155) **Midcourse guidance is necessity for interplanetary travel**. L. T. Seaman. *Missiles and Rockets*, **5** (6), 40, 43, 45–6 (9 *Feb.*, 1959).

(156) **Space navigation poses new requirements**. F. Stevens. *Missiles and Rockets*, **5** (6), 37, 39 (9 *Feb.*, 1959).

(157) **Application of astronomical perturbation techniques to the return of space vehicles**. R. M. L. Baker. *ARS J.*, **29**, 207–11 (*March*, 1959). (12 *refs.*)

(158) **A short form method for determining near-circular orbit quantities**. J. N. Benezra. *ARS J.*, **29**, 216–9 (*March*, 1959). (3 *refs.*)

(159) **Motion units to simplify space travel computations**. B. Boyd. *ARS J.*, **29**, 216 (*March*, 1959).

(160) **Attitude control for space vehicles**. M. B. T. George. *Astronautics*, **4** (3), 34–5, 106–7 (*March*, 1959).

(161) **An attitude control system for space vehicles**. W. Haeussermann. *ARS J.*, **29**, 203–7 (*March*, 1959). (6 *refs.*)

(162) **Interplanetary trajectories under low thrust radial acceleration**. J. Copeland. *ARS J.*, **29**, 267–71 (*April*, 1959). (4 *refs.*)

(163) **Circular orbit stability in the oblate Earth's equatorial plane**. M. H. Hewitt. *ARS J.*, **29**, 295–6 (*April*, 1959).

(164) **On-off control system for attitude stabilization of a space vehicle**. J. S. Pistiner. *ARS J.*, **29**, 283–9 (*April*, 1959). (2 *refs.*)

7—PROPULSION

.1 *General*

(165) **Propulsion**. J. Grey. *Aviation Age*, **28** (9), 36–7, 39–43 (*March*, 1958). A brief review of all known methods of rocket propulsion: chemical, nuclear, ion, photon, etc.

(166) **British rocket and ramjet engines**. A. D. Baxter and S. W. Greenwood. *Aircraft Engng.*, **30**, 252–68 (*Sept.*, 1958). A general survey of this work, giving the history of British work on liquid-propellent rocket engines and their application to aircraft and missiles. The design of both liquid- and solid-propellent rockets is discussed; there are numerous examples and illustrations. The paper concludes with a parallel account of the progress and applications of ram-jets and pulse-jets. (16 *refs.*)

(167) **Propulsion systems for space flight**. W. R. Corliss. 312 pp., *McGraw-Hill, London and New York* (1959). Propulsion-system performance and space missions. Environment of space. Power generation in space. Thermal propulsion systems. Electrical propulsion systems. Nuclear-particle generators. Photonic propulsion systems. Propulsion systems using natural force fields. Summary and evaluation. Glossary of terms. Table of symbols. Bibliography.

.2 *Ram-Jets and Air-Breathing Engines*

(168) **Atmosphere breathing engines in astronautics**. S. W. Greenwood and D. S. Carton. *College of Aeronautics Note No.* 88, 22 pp. (*Oct.*, 1958). (10 *refs.*)

(169) **Photochemistry of the upper atmosphere as a source of propulsive power**. A. F. Charwat. *ARS J.*, **29** (2), 108–14 (*Feb.*, 1959). (22 *refs.*)

(170) **Ramjet combustion**. R. Breitweiser. *Astronautics*, **4** (4 Pt. 1), 44–5, 87–8, 90 (*April*, 1959).

(171) **A future for hypersonic ramjets**. G. L. Dugger. *Astronautics*, **4** (4 Pt. 1), 38–9, 114–7 (*April*, 1959).

(172) **A monopropellent air-turborocket**. J. W. Mullen. *Astronautics*, **4** (4 Pt. 1), 36–7, 72 (*April*, 1959).

(173) **Ramjet trends**. E. Perchonok. *Astronautics*, **4** (4 Pt. 1), 40–1, 100–2 (*April*, 1959).

.3 *Chemical Rockets*

[*See also* abstract no. 292]

GENERAL

(174) **Liquids vs. solids: the $64,000 question of rocket development**. K. R. Stehling. *Aviation Age*, **29** (6), 22–3, 90–1, 94–5 (*June*, 1958).

(175) **Instrumentation plays vital role in rocket development**. K. R. Stehling. *Aviation Age*, **30** (1), 20–1, 76–8, 80–1 (*July*, 1958). Indicates the importance of accurate measurement in rocket engine development, gives data on devices for measuring flow rate, pressure, thrust and temperature, and for recording their outputs.

(176) **Rocket throttling: tricky but not impossible**. K. R. Stehling. *Space-Aeronautics*, **30** (6), 66–71 (*Dec.*, 1958). Possible methods of varying the thrust of liquid- and solid-propellent rockets.

(177) **Technical development in propulsion in the Soviet Union**. D. J. Ritchie. *Bendix Aviation Corp., Research Labs. Div. Rept. No.* 1212, 71 pp. (1959). (59 *refs.*)

(178) **Propulsion by rocket engine**. *Missili*, **1**, 65–72 (*Feb.*, 1959). (*In Italian.*) Popular.

(179) **Transducer frequency response evaluation for rocket instability research**. C. R. Tallman. *ARS J.*, **29** (2), 119–22 (*Feb.*, 1959). (4 *refs.*)

(180) **Rocket engine developments**. D. S. Carton. *Aeroplane*, **96**, 163–6 (6 *Feb.*, 1959). A review of progress in the design of rocket engines, methods of production of solid- and liquid-propellent rocket combustion chambers, and of injectors for liquids. A Table of rocket engines in production is given.

(181) **Thrust of a conical nozzle**. E. M. Landsbaum. *ARS J.*, **29** (3), 212–3 (*March*, 1959).

(182) **Educating the amateur rocketeer**. *Astronautics*, **4** (4 Pt. 1), 33, 96 (*April*, 1959).

(183) **The rocket: an old idea, an old challenge**. S. B. Kramer and N. Putnam. *Astronautics*, **4** (4 Pt. 2), 15–17 (*April*, 1959).

(184) **Rocket propulsion**. C. J. Marsel. *Astronautics*, **4** (4 Pt. 2), 7–11 (*April*, 1959). (6 *refs.*)

(185) **Rockets and amateurs**. G. P. Sutton. *Astronautics*, **4** (4 Pt. 2), 12–14 (*April*, 1959). [See also *J. M.I.T. Rocket Res. Soc.*, **5** (3), 7–13 (*April*, 1959).]

(186) **Rocket research in Canada**. R. F. Wilkinson. *Canad. Aeronaut. J.*, **5** (4), 138–42 (*April*, 1959). The rocket engine is compared with other propulsion means, conditions which affect research in Canada are discussed. Work is proceeding on composite solid propellents case-bonded in motors up to 17 in. dia.

(187) **Gold being used on steering jets to ward off cosmic bombardment**. *Amer. Metal Market*, **67** (168), 5 (31 *Aug.*, 1960). Au-plated thrust controllers developed by Bendix Corp. for Discoverer satellites.

.31 SOLID-PROPELLENT ROCKETS.

(188) **Solid propellant rockets, second stage**. A. J. Zaehringer. $8.00, 303 pp. *American Rocket Co., Wyandotte, Mich., U.S.A.* (1958). New edition, with five new chapters.

(189) **How to estimate solid propellant rocket performance**. S. Dobrin. *Aviation Age*, **28** (8), 70–3 (*Feb.*, 1958).

(190) **Suitable shapes for solid propellents**. U. T. Bödewadt. *Raktech. Raumforsch.*, **3**, 19–24 (*Jan.–March*, 1959). (*In German.*)

(191) **Surveillance of solid propellant rockets**. C. Boyars. *ARS J.*, **29**, 148–50 (*Feb.*, 1959).

(192) **Solid propellent rockets. 2.** G. Marcozzi. *Alata*, **15** (164), 59–60 (*Feb.*, 1959). (*In Italian.*) (3 *refs.*)

(193) **Complication for solids: thrust-direction control.** N. L. Baker. *Missiles and Rockets*, **5** (6), 23–5 (9 *Feb.*, 1959).

(194) **Dimensions of a charge of solid propellent for a rocket of the internal star type.** A. Angeloni. *Missili*, **1** (2), 23–35 (*April*, 1959). (*In Italian.*) (9 *refs.*)

(195) **Construction of a small, relatively safe solid-propellant rocket.** L. E. Batchman, J. M. Kauffman and D. W. Steele. *J. M.I.T. Rocket Res. Soc.*, **5** (3), 1–5 (*April*, 1959).

(196) **The future for solid propellant rockets.** K. W. Pearce. *J. Roy. Aero. Soc.*, **63** (580), 221–6 (*April*, 1959). Improvements in performance during the past decade; methods used for control of thrust direction, cut-off and magnitude. (21 *refs.*)

(197) **Some thermal stress design data for rocket grains.** M. L. Williams. *ARS J.*, **29**, 260–7 (*April*, 1959). (18 *refs.*)

(198) **Aerojet working on 5-meg. solid.** *Missiles and Rockets*, **6** (2), 13 (11 *Jan.*, 1960). Aerojet General is proposing a solid-propellent boost capable of placing 25 tons of useful payload in orbit. It is stressed that reliability is not a function of size in solid-propellent motors.

(199) **Rocketdyne details solid booster plan.** J. Holmes. *Missiles and Rockets*, **6** (6), 31 (8 *Feb.*, 1960). Three methods of producing a 2,000,000 lb.-thrust solid motor are compared.

(200) **Navair proposes all-plastic rocket.** F. G. McGuire. *Missiles and Rockets*, **6** (6), 25–29 (8 *Feb.*, 1960). A solid-propellent motor utilizing all plastic parts is presented. Tables comparing properties of space materials and thermal stability of polymers.

·32 Liquid-Propellent Rockets.

(201) **Rocket pumps have reached high efficiency.** K. R. Stehling. *Aviation Age*, **29** (4), 32–3, 35, 37–8, 41–2 (*April*, 1958). Design features of liquid-propellent pumps and their power sources.

(202) **On the measurement of high frequency stability limits in a liquid bipropellent rocket.** L. Crocco and J. Grey. *Aerotecnica*, **38** (3), 135–44 (*June*, 1958). (*In Italian.*) A rocket of variable length was used to find the stability limits for longitudinal high-frequency oscillation. Ignition lag parameters of the chamber were checked independently. The dependence of stability limits on nozzle profile and chamber pressure agrees with the Crocco-Cheng theory, and zones of instability also predicted by that theory for increasing lengths of chamber were found. (8 *refs.*)

(203) **On the development of H_2O_2 rocket engines.** D. Hurden. *Raktech. Raumforsch.*, **3**, 9–13 (*Jan.–March*, 1959). (*In German.*)

(204) **Adiabatic wall temperature due to mass transfer cooling with a combustible gas.** G. W. Sutton. *ARS J.*, **29**, 136–7 (*Feb.*, 1959). (7 *refs.*)

(205) **Determination of transient pressure flow relationship by momentum measurements.** E. J. Croke and J. Grey. *ARS J.*, **29**, 213–4 (*March*, 1959). (5 *refs.*)

(206) **Liquid propellent motors dominate the space scene.** A. J. Zaehringer. *Alata*, **15** (165), 50–2 (*March*, 1959). (*In Italian.*)

(207) **Performance problems in large rocket engines.** S. L. Bragg. *Coventry Engng. Soc. J.*, **40** (2), 14–24 (*March–April.* 1959).

(208) **The transparent chamber rocket motor as a research tool.** J. R. Roth. *J. M.I.T. Rocket Res. Soc.*, **5** (3), 14–23 (*April*, 1959). (5 *refs.*)

(209) **Throttleable engine prolongs aircraft life.** F. G. McGuire. *Missiles and Rockets*, **5** (17), 23–5 (27 *April*, 1959).

·33 Propellents.

(210) **Measurement of ignition delay under simulated altitude conditions for liquid propellent rockets.** P. Sarrat. *Rech. Aéronaut.*, **62**, 15–25 (*Jan.*, 1958). (*In French.*) Tests in an altitude chamber. Results are compared with those obtained in the laboratory. (3 *refs.*)

(211) **Reliability and low cost propellant production.** I. Stambler. *Aviation Age*, **28** (8), 112–16 (*Feb.*, 1958).

(212) **Dilution of liquid oxygen when nitrogen is used for pressurization.** T. J. Walsh, R. R. Hibbard and P. M. Ordin. *N.A.C.A. Res. Memo. E58A03a*, 17 pp. (*April*, 1958).

(213) **Dilution of cryogenic liquid rocket propellants during pressurised transfer.** S. Greenfield. *Aircraft Engng.*, **30**, 210–12 (*July*, 1958). Dilution of liquid oxygen with nitrogen affects its performance as a propellent. The paper describes methods of measuring contamination and reducing its occurrence.

(214) **Good handling techniques eliminate LOX problems.** D. Joliceour. *Aviation Age*, **30** (1), 60–3, 65 (*July*, 1958). Methods used by Rocketdyne to handle liquid oxygen in large quantities.

(215) **A rapid method for estimation of specific impulse.** B. A. Free and S. F. Sarner. *ARS J.*, **29**, 64–7 (*Jan.*, 1959). (6 *refs.*)

(216) **A ballistic bomb method for determining the experimental performance of rocket propellants.** D. N. Griffin, C. F. Turner and G. T. Angeloff. *ARS J.*, **29**, 15–19 (*Jan.*, 1959).

(217) **Improvements in the operating characteristics of n-propyl nitrate.** R. W. Lawrence and W. P. Knight. *ARS J.*, **29**, 29–32 (*Jan.*, 1959). Use in gas generators. (9 *refs.*)

(218) **The ignition behavior of various amines with white fuming nitric acid.** R. L. Schalla and E. A. Fletcher. *ARS J.*, **29**, 33–9 (*Jan.*, 1959). (8 *refs.*)

(219) **Some developments in the field of chemical propellants.** W. S. Wood. *Chemistry and Industry* (5), 136–42 (31 *Jan.*, 1959). (34 *refs.*)

(220) **Performance limitations of classical solid propellents.** R. Engel. *Raktech. Raumforsch.*, **3**, 14–18 (*Jan.–March*, 1959). (*In German.*)

(221) **High energy composite propellant systems.** K. Klager. *Missile Des. Dev.*, **5** (2), 16–17, 19 (*Feb.*, 1959).

(222) **New propellents.** A. J. Zaehringer. *Alata*, **15** (164), 54–5 (*Feb.*, 1959). (*In Italian.*) Solids.

(223) **Isothermal compressibility of liquid oxygen and RP-1.** G. T. Y. Chao. *ARS J.*, **29**, 199–203 (*March*, 1959). (14 *refs.*)

(224) **Performance calculations for hybrid nuclear-chemical rocket propulsion systems.** L. Green and J. M. Carter. *ARS J.*, **29**, 180–6 (*March*, 1959). (24 *refs.*)

(225) **Compression sensitivity of monopropellants.** G. A. Mead. *ARS J.*, **29**, 192–8 (*March*, 1959). (3 *refs.*)

(226) **A note on liquid and solid propellants for rockets.** E. G. D. Andrews and A. W. T. Mottram. *J. Roy. Aero. Soc.*, **63** (580), 265 (*April*, 1959). Stresses that both liquid and solid-propellent rockets will find increasing fields of application in the future.

(227) **Recent advances in cryogenic engineering.** R. B. Jacobs. *ARS J.*, **29**, 245–51 (*April*, 1959). (56 *refs.*)

(228) **Storables stir renewed interest.** C. M. Beighley. *Missiles and Rockets*, **6** (7), 30–33 (15 *Feb.*, 1960). Prospects of converting Titan to storable propellent; a combination of nitrogen tetroxide oxidizer and a 50–50 UDMH-hydrazine fuel mix would give a S.I. of 288 sec. compared with the present LOX/hydrocarbon giving 300. Additional propellent capacity and density is expected to compensate. Tables giving performance data of propellent are included.

(229) **Hydrogen for the space age.** R. J. Coar and C. H. King. *Astronautics*, **5** (3), 26–27, 76–78 (*March*, 1960). Suggests that the hydrogen-oxygen rocket will soon be practicable and gives details of increased payloads obtainable with this system.

.4 Nuclear Rockets, Working Fluid

[*See* abstracts nos. 105, 224]

.5 Ion Rockets

[*See also* abstract no. 106]

(230) **Ion propulsion: electric power for spaceflight.** K. R. Stehling. *Aviation Age*, **28** (7), 38–40, 42–3 (*Jan.*, 1958). (3 *refs.*)

8—MISSILES

.1 *General*

[*See also* abstracts nos. 54, 70, 292]

(231) **Rockets and missiles**. M. Allward and J. W. R. Taylor. 36 pp., 2s. 6d. *Ian Allen, London* (1958). Revised edition of **ABC of rockets and space-travel**.

(232) **Rockets and missiles**. E. Bergaust. $2.00, 48 pp. *Putnam, N.Y.* (1958). Second printing.

(233) **A comparative analysis of the performance of long-range hypervelocity vehicles**. A. J. Eggers, H. Allen, and S. E. Neice. *N.A.C.A. Rept.* 1382 (1958). A comparison of ballistic, skip- and glide-vehicles, and the supersonic long-range aircraft. Makes proposals for manned vehicles of these kinds.

(234) **Red missile arsenal packs long range punch**. *Aviation Age*, **29** (4), 20–1, 94–6, 98–101 (*April*, 1958). Tables giving characteristics of Russian missiles and high-altitude rockets.

(235) **Incremental step vehicles approach ideal rocket performance**. H. R. Wahlin. *Aviation Age*, **29** (6), 166–72 (*June*, 1958).

(236) **Step-rockets**. J. Schmidtmayer. *Acta Technica*, 379–403 (1959). (23 *refs.*)

(237) **Optimization of rockets for maximum payload energy**. D. M. Cole and M. A. Manese. *ARS J.*, **29**, 71–3 (*Jan.*, 1959).

(238) **Frictional electricity in missile systems**. P. Molmud. *ARS J.*, **29**, 73–5 (*Jan.*, 1959). (15 *refs.*)

(239) **A look at Britain's missile program**. R. H. Rodwell. *Air Force Mag.*, **42** (1), 44–9 (*Jan.*, 1959).

(240) **Budget holds $7 billion for missiles**. C. Newlon. *Missiles and Rockets*, **5** (4), 21–3 (26 *Jan.*, 1959). Breakdown of Fiscal Year 1960 U.S. budget.

(241) **Effect of acceleration on the longitudinal dynamic stability of a missile**. E. V. Laitone. *ARS J.*, **29**, 137–9 (*Feb.*, 1959). (8 *refs.*)

(242) **Lockheed emphasis is systems management**. W. O. Miller. *Missiles and Rockets*, **5** (5), 16–18 (2 *Feb.*, 1959). Lockheed's activities.

(243) **Missile test ranges of the United States. II**. *Holloman Monthly News Bull.*, **3** (5), 1–5, 11–12 (*March*, 1959). (58 *refs.*)

(244) **General equation for rocket velocity**. S. Rubin. *ARS J.*, **29**, 219–20 (*March*, 1959). (1 *ref.*)

(245) **World rapidly adding more missile ranges**. W. O. Miller. *Missiles and Rockets*, **5** (10), 15–17 (9 *March*, 1959).

(246) **Vibration testing of new missiles saves money and time**. C. G. Pierce. *Missiles and Rockets*, **5** (17), 17–20 (27 *April*, 1959).

(247) **[Papers presented] At St. Louis' seminar on missiles**. *Metals Rev.*, **32** (11), 12 (*Nov.*, 1959).

(248) **Interpreting reliability by fitting theoretical distributions to failure data**. W. S. Connor. *Ind. Engng. Chem.*, **52** (2), 59A, 60A (*Feb.*, 1960). Failure history of a component of a missile subsystem is discussed as example.

(249) **Russia's big missile bases**. J. Baar and W. E. Howard. *Missiles and Rockets*, **6** (7), 25–9 (15 *Feb.*, 1960). Lists with coloured map all known Soviet missile bases, totalling 10 I.C.B.M. and 30 I.R.B.M. bases.

.2 *Short-Range*

(250) **Air-to-air Firestreak is designed for simple aerodynamic control**. I. Stambler. *Aviation Age*, **28** (7), 98–103 (*Jan.*, 1958).

(251) **Falcon airframe uses die casting, magnesium structure**. I. Stambler. *Space/Aeronautics*, **30** (6), 18–19, 80, 82, 84, 86–7 (*Dec.*, 1958). Main structural components of this missile, materials used and methods of manufacture.

(252) **New arms for Fighter Command**. R. R. Rodwell. *Aeronautics*, **39** (5), 22–6 (*Jan.*, 1959). Bloodhound and Firestreak.

.3 *Ballistic*

(253) **Turbojet may serve as I.C.B.M. booster**. *Aviation Wk.*, **68** (4), 36 (27 *Jan.*, 1958). General Electric Company proposal for air-breathing boost motor, to be about 50% of takeoff weight.

(254) **Missile spending spurred by Soviets**. M. Yaffee. *Aviation Wk.*, **68** (9), 91–4, 97, 101, 103 (3 *March*, 1958). Progress on American ballistic and space-research vehicles in the light of the progress recently revealed by Russian satellite launchings.

(255) **Support complex surrounds Atlas missile launch site**. *Aviation Wk.*, **68** (11), 22–3 (17 *March*, 1958). Pictures of Atlas launching and equipment at Cape Canaveral.

(256) **Missile development in a hurry: Navy's Polaris I.R.B.M.** V. DeBasi. *Aviation Age*, **29** (6), 20–1, 78, 82, 86, 88–9 (*June*, 1958).

(257) **Capsule collects data during re-entry**. *Space-Aeronautics*, **30** (6), 150–1, 153 (*Dec.*, 1958). Data-storing capsule used in Thor and Atlas firings. Contains a tape recorder and a beacon to assist recovery, mounted in resilient foam in a glass-resin shell.

(258) **Simplified preliminary design procedures in ballistic missile, satellite launcher and space ship design**. D. Ritchie. *Bendix Aviation Corp., Research Labs. Div. Rept. No.* 1223, 125 pp. (1959). (21 *refs.*)

(259) **America's supersonic cargo rocket**. W. S. Griswold. *Pop. Sci.* **174** (4), 115–7, 236 (*April*, 1959). Popular description of Lobber.

.4 *Upper Atmosphere Research*

[*See also* abstract no. 124]

(260) **A history of Project "Charm."** A. B. Barnes. *Proc. Canad. Astronaut. Soc.*, **1** (1), 45–56 (*Feb.*, 1959).

(261) **Skylark: a high-altitude research rocket**. E. B. Dorling *Discovery*, **20**, 115–9 (*March*, 1959).

.5 *Trajectories*

(262) **Ballistic missile trajectories**. P. A. Lapp. *Proc. Canad. Astronaut. Soc.*, **1** (1), 16–38 (*Feb.*, 1959). (3 *refs.*)

(263) **Minor circle flight for boost glide vehicles**. W. H. T. Loh. *ARS J.*, **29**, 300–1 (*April*, 1959). (1 *ref.*)

.6 *Guidance and Control*

(264) **Directly double-integrating accelerometer looks good for inertial guidance**. K. E. Pope. *Aviation Age*, **28** (7), 50–5 (*Jan.*, 1958).

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